

TITANIUM

A MATERIALS SURVEY

BY JESSE A. MILLER

* * * * * Information Circular 7791



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OFFICE OF THE DIRECTOR



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON 25, D. C.

Hon. Arthur S. Flemming
Director
Office of Defense Mobilization
New GAO Building
Washington 25, D. C.

My dear Mr. Flemming:

Copies of the Materials Survey - Titanium, prepared by the Bureau of Mines with the cooperation of the Geological Survey for the Office of Defense Mobilization, are being forwarded to your office.

This report is the second Materials Survey to be completed under the terms of the April 15, 1955, agreement between the Department of the Interior and the Office of Defense Mobilization which assigned responsibility to Interior for preparation and revision of Surveys covering 45 mineral commodities. The Titanium report is the fourteenth Materials Survey published by the Bureau of Mines, the first twelve having been prepared under an agreement made in 1950 with the National Security Resources Board.

Manuscript revisions proposed by reviewing officials of the Office of Defense Mobilization have been incorporated in the Survey.

Sincerely yours,

Marling J. Ankeny
Director

Foreword

The Materials Survey series is being prepared to provide comprehensive fundamental data on strategic and critical materials required for military and essential civilian consumption. The data are for use primarily by Government officials responsible for the National Security. This volume covers the commodity titanium, the main emphasis being placed upon titanium metal and rutile. Ilmenite and titanium slag are also included, inasmuch as they are possible substitutes for rutile in some uses.

This volume was prepared under the general direction of Charles W. Merrill, Chief, Division of Minerals, Federal Bureau of Mines, and under the direct supervision of Frank J. Cservenyak, Chief, Branch of Light Metals.

The element titanium and its compounds are used in a variety of end products; therefore some of the chapters in this survey deal exclusively with titanium metal, while others include titanium minerals and various intermediate products. *A cutoff date of June 30, 1955, has been established for this survey.* Information that has appeared after this date has not been incorporated.

CHARLES W. MERRILL,
Chief, Minerals Division.

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TITANIUM¹

A MATERIALS SURVEY

BY

JESSE A. MILLER²

Summary and Introduction

ALTHOUGH the element titanium was discovered by William Gregor in 1790, over a hundred years passed before it was put to commercial use. The first commercial application of titanium was as an alloy additive to iron and steel, and the first ferroalloys were produced domestically in 1906. Titanium pigments were developed somewhat later and have been produced in the United States since 1918. The use of titaniferous material in welding-rod coatings first gained acceptance in the mid-30's. The metal titanium has only had commercial importance since 1948; domestic production for that year was 10 tons.

The relative importance of these major uses of titanium in various forms may be gaged by the consumption of titanium dioxide (TiO_2) for these purposes in 1954. Of a total of 440,000 short tons of TiO_2 consumed in 1954, 95 percent of the total was consumed for pigments; 2 percent for welding-rod coatings; 1 percent for non-titanium-base alloys and carbide; and 2 percent for miscellaneous uses. The titanium-metal industry is in its infancy, but it has more than doubled its output every year from 1948 to 1954, reaching 5,370 short tons in 1954.

The two most important titanium-ore minerals are ilmenite (FeTiO_3) and rutile (TiO_2). Ilmenite and rutile are mainly used in different end products, substitution of one for the other being limited by economic and technical considerations. A titanium slag produced in Canada since 1951 by smelting a hematite-ilmenite ore is competing with both ilmenite and rutile as a source of TiO_2 . Ninety-nine percent of the ilmenite consumed in the United States in 1954 was used to produce titanium pigments. The major use of rutile was in producing welding-rod coatings and titanium tetrachloride for metal. Titanium slag was used for pigments and welding-rod coatings and (experimentally) in the production of metal. Ilmenite, rutile, and manufactured TiO_2 were employed in non-titanium-base alloys and carbide, ceramics, and a variety of miscellaneous uses.

The major factors that determine the use of a particular mineral are the price of the raw material and its TiO_2 content. Ilmenite concentrate containing 59.5 percent TiO_2 sold for around \$18 to \$20 per short ton f. o. b. east coast in June 1955. Rutile concentrate containing 94 percent TiO_2 sold for around \$200 per short ton f. o. b. east coast at this time. Titanium slag with a TiO_2 content of about 70 percent sold for \$36 per gross ton f. o. b. Sorel, Canada. Manufactured TiO_2 made from ilmenite could serve as a substitute for rutile in many applications, but its price of around 22 cents per pound prohibits this possibility except in an emergency. The high iron content of ilmenite offers many technical obstacles in its use as a substitute for rutile.

World production of ilmenite in 1954 was 1,092,000 short tons, with the United States producing 50 percent of this total. World production of rutile

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² Physical scientist, Bureau of Mines.

in this same year was 57,800 short tons, and the United States supplied only 13 percent of the total. The chief producers of ilmenite in 1954 were the United States, India, Norway, and Malaya. If titanium slag is grouped with ilmenite, Canada becomes the fourth largest producer in 1954 after Norway. Rutile was produced almost exclusively by Australia and the United States in 1954.

The United States is in a favorable position with regard to ilmenite, having supplied 66 percent of its needs in 1954 from mines in New York, Florida, and Idaho. Imports in 1954 were chiefly from India and Canada (slag). The United States depends largely upon Australia for its supplies of rutile but supplied about 35 percent of its 1954 needs from deposits in Florida. The extent to which world production of rutile can be expanded appears to be limited, so that any major expansion in the titanium-metal industry will probably be premised upon the use of ilmenite or titanium slag rather than upon rutile.

In early 1955 the United States was the leading world producer of titanium metal; the only other country known to be producing it at that time on a commercial scale was Japan. In England the British were constructing a plant with a capacity of 1,500 tons to begin operation in 1955. Thus far the metal has been made commercially by magnesium reduction of titanium tetrachloride. In this process a spongy mass of titanium is formed, and this material must then be consolidated in some fashion. The chief method of consolidation is by double arc melting, employing a consumable electrode of titanium and a water-cooled copper crucible.

The high price of titanium sponge and mill products has tended to limit the use of the metal to those applications in which the additional price was justified by certain of titanium's unique properties. Utilization of the metal by private industry has been minor, being confined to those uses where the corrosion resistance of titanium was of value. The chief use of titanium has been by the military establishment, especially in aircraft, where the high strength-weight ratio of the metal at elevated temperatures justified its use as a structural metal. With a density of only 57 percent that of steel, titanium metal and its alloys compare favorably in strength with certain steels.

A downward trend in the price of sponge began in 1954. From 1948 to 1954 commercially pure titanium sold for \$5 per pound. Two price reductions in 1954 and one reduction by April 1955 resulted in the price being quoted on April 1, 1955, at \$3.95 per pound for Grade A-1 and \$3.50 per pound for Grade A-2.

Although titanium has a melting point higher than that of steel, its strength falls rapidly above 800° F. Above 1,300° F. titanium metal absorbs oxygen and nitrogen from the atmosphere, with a resultant embrittlement of the metal. For these reasons, titanium is used mainly in those applications in which the temperature does not exceed 800° F. Any processing or fabricating that is done at elevated temperatures must be carried out either under a vacuum or under an inert atmosphere to avoid atmospheric contaminants.

Other characteristics of titanium that present difficulties in fabrication are its tendency to seize and gall, its low coefficient of thermal conductivity, its low coefficient of thermal expansion, and the difficulty of properly lubricating the metal in some fabricating operations. Many fabrication problems have been solved by Government- and industry-sponsored research and development projects. Solution of these problems will result in lower cost for the finished metal and in more widespread acceptance of titanium by industry.

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CHAPTER 1. CONSUMPTION, PROPERTIES, AND USES

ORES: CONSUMPTION AND USES

The two chief ore minerals of titanium—rutile and ilmenite—are discussed in chapter 2; however, it is necessary to note at this point that rutile (whose formula is TiO_2) theoretically contains 100 percent TiO_2 , while unaltered ilmenite (whose formula is FeTiO_3) theoretically contains only 53 percent TiO_2 . Rutile concentrate usually contains 92 to 98 percent TiO_2 and ilmenite concentrate (including weathered ilmenites) varies from 45 to 65 percent TiO_2 . Consumption of these two minerals may best be compared on the basis of TiO_2 content rather than on gross weight. To arrive at some idea of the magnitude of consumption of titanium minerals in the United States, it may be noted that consumption of ilmenite in 1954 was 680,000 short tons, with a TiO_2 content of 353,000 short tons, whereas the consumption of rutile was 21,000 short tons, containing 19,000 short tons of TiO_2 . Since 1951 the United States has imported from Canada a titanium slag that contains about 70 percent TiO_2 . Consumption of slag in 1954 was 101,000 short tons. In some tables this slag is grouped with the ilmenite because it is smelted from an ilmenite-hematite ore. Slag of this type will become increasingly important as a source of titanium in the future.

TABLE 1.—United States consumption of titanium concentrate, by uses, 1954

Use	Estimated TiO_2 content, short tons	Percent of total
Titanium dioxide (pigment).....	420, 850	94. 9
Welding-rod coatings.....	8, 670	1. 9
Alloys and carbide.....	4, 766	1. 1
Ceramics, fiberglass, metal, titanium-base alloys, chemical, and other....	9, 383	2. 1
Total.....	443, 669	100. 0

Domestic consumption and uses of titanium concentrate in 1954 are shown in table 1.

Figures on the domestic consumption of titanium concentrate are divided into three categories: Ilmenite, titanium slag, and rutile. This is necessary because of the difference in TiO_2 content of these various sources of titanium and because they are used in manufacturing different products. Ilmenite, which made up 79.5 percent of the total titanium dioxide consumed in 1954, is used mainly in manufacturing pigments. Rutile, although furnishing only 4.5 percent of the titanium dioxide consumed in 1954, is very important in the production of titanium metal and welding-rod coatings. Titanium slag, making up 16.0 percent of the titanium dioxide consumed, is intermediate between rutile and ilmenite, being used for pigments and welding-rod coatings and (experimentally) in the production of metal. Technologic and economic factors influence the use of these various materials. Ilmenite concentrate in June 1955 sold for \$18 to \$20 per short ton, f. o. b. east coast; rutile concentrate is priced at \$200 per short ton, f. o. b. east coast; and titanium slag is priced at \$36 per ton, f. o. b. Sorel, Quebec, Canada. Although ilmenite is the cheapest source of titanium, its iron content complicates its processing for metal, fiberglass, welding-rod coatings, and other uses. Titanium slag has been assuming increasing importance because it has a much lower iron content than ilmenite and is much cheaper than rutile.

Consumption of ilmenite, rutile, and titanium slag, by uses, in recent years is compared in table 2. Alloys referred to in these tables are non-titanium-base alloys unless otherwise stated.

Tables 3 and 4, respectively, show, on a gross tonnage basis, the total annual domestic consumption and the domestic consumption, by uses, of ilmenite and rutile from 1941 to 1954. Tables 3 and 4 have been summarized graphically in figures 1 through 3. Tables 5 and 6, partial recapitulations of tables 3 and 4, show the estimated titanium dioxide content of ilmenite, rutile, and manufactured titanium dioxide domestically consumed in the manufacture of welding-rod coatings (table 5) and alloys and carbide (table 6).

TABLE 2.—Consumption of titanium concentrates in the United States, 1941-52 total and 1953-54, by products, in short tons ¹

Product	Ilmenite		Titanium slag		Rutile	
	Gross weight	Estimated TiO ₂ content	Gross weight	Estimated TiO ₂ content	Gross weight	Estimated TiO ₂ content
1941	275, 106	150, 966			6, 361	5, 986
1942	257, 535	141, 412			10, 616	9, 952
1943	302, 822	142, 868			17, 634	16, 451
1944	360, 941	175, 475			14, 813	13, 837
1945	381, 178	187, 580			9, 791	9, 144
1946	404, 283	202, 663			7, 134	6, 670
1947	479, 524	250, 859			7, 692	7, 803
1948	565, 000	300, 408			10, 230	9, 488
1949	² 512, 834	² 269, 892			9, 662	8, 971
1950	² 679, 244	² 351, 675			11, 721	10, 869
1951	² 713, 363	² 373, 037			17, 227	16, 018
1952	² 682, 850	² 351, 553	24, 236	16, 746	18, 317	17, 353
1953						
Pigments (mfg. TiO ₂) ³	² 676, 238	² 348, 984	73, 324	52, 368		
Welding-rod coatings	990	584			10, 476	9, 812
Alloys and carbide	9, 974	4, 979			2, 394	2, 279
Ceramics	5	3			317	295
Miscellaneous	19	11	⁴ 204	⁴ 143	⁵ 6, 832	⁵ 6, 502
Total	² 687, 226	² 354, 561	73, 528	52, 511	20, 019	18, 888
1954						
Pigments (mfg. TiO ₂) ³	² 673, 506	² 349, 857	100, 670	70, 993		
Welding-rod coatings	845	501			8, 817	8, 169
Alloys and carbide	5, 535	2, 779			2, 069	1, 987
Ceramics	9	5			372	348
Miscellaneous	8	4	⁴ 155	⁴ 109	⁵ 9, 405	⁵ 8, 927
Total	² 679, 903	² 353, 146	100, 825	71, 102	20, 663	19, 431

¹ Data not available before 1941.² Includes a mixed product containing altered ilmenite, leucoxene, and rutile used to make pigments and metal.³ "Pigments" include all manufactured titanium dioxide.⁴ Includes consumption for welding-rod coatings and research purposes.⁵ Includes consumption for chemicals, metal, and fiberglass.

TABLE 3.—United States consumption of ilmenite concentrate (gross weight), by uses, 1941–54 ¹

Year	Total consumption, short tons	Average estimated TiO_2 , percent	Pigments (manufactured TiO_2)		Welding-rod coatings		Alloys and carbide		Miscellaneous	
			Short tons	Percent of total	Short tons	Percent of total	Short tons	Percent of total	Short tons	Percent of total
1941	275, 106	54. 9	267, 944	97. 4	58	(²)	³ 7, 104	2. 6		
1942	257, 535	54. 9	244, 465	94. 4	56	(²)	11, 802	4. 6	⁴ 1, 212	0. 5
1943	302, 822	47. 2	290, 573	96. 0	194	(²)	10, 583	3. 5	⁴ 1, 472	. 5
1944	360, 941	48. 6	349, 505	96. 8	148	(²)	10, 174	2. 8	⁴ 1, 114	. 3
1945	381, 178	49. 2	371, 691	97. 5	115	(²)	8, 611	2. 3	⁴ 761	. 2
1946	404, 283	50. 1	399, 042	98. 7	105	(²)	4, 685	1. 2	⁴ 451	. 1
1947	479, 524	52. 3	473, 154	98. 7	144	(²)	5, 972	1. 2	254	(²)
1948	565, 000	53. 2	558, 448	98. 8	145	(²)	6, 377	1. 1	30	(²)
1949	⁵ 512, 834	52. 6	⁵ 507, 658	98. 9	165	(²)	4, 969	1. 0	42	(²)
1950	⁵ 679, 244	51. 8	⁵ 671, 335	98. 8	210	(²)	7, 666	1. 1	33	(²)
1951	⁵ 713, 363	52. 3	⁵ 703, 068	98. 6	258	(²)	10, 024	1. 4	13	(²)
1952	⁵ ⁶ 682, 850	51. 5	⁵ 670, 829	98. 2	719	0. 1	11, 293	1. 7	9	(²)
1953	⁵ ⁶ 687, 226	51. 6	⁵ 676, 238	98. 4	990	. 1	9, 974	1. 4	24	(²)
1954	⁵ ⁶ 679, 903	51. 9	⁵ 673, 506	99. 1	845	. 1	5, 535	. 8	17	(²)
1955										
1956										
1957										

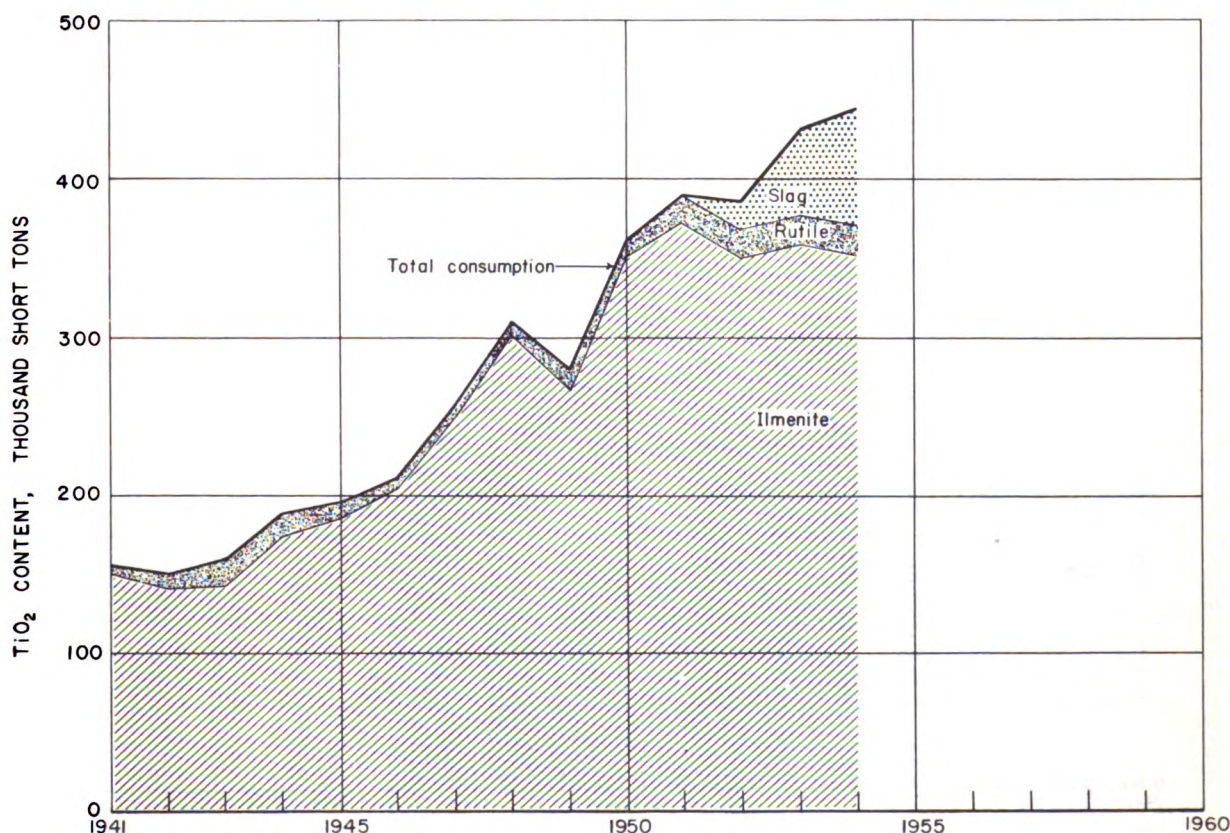
¹ Data not available before 1941.² Less than 0.1 percent.³ Alloys only.⁴ Consists of ilmenite used as a steel flux.⁵ Includes a mixed product containing altered ilmenite, leucoxene, and rutile used to make pigments and metal.⁶ In addition, titanium slag consumption for pigments, welding-rod coatings, and experimental purposes totaled 24,236 short tons in 1952, 73,528 short tons in 1953, and 100,825 short tons in 1954. (See table 2.)

FIGURE 1.—United States Consumption of Ilmenite and Rutile Concentrates and Titanium Slag, 1941–54.

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TABLE 4.—United States consumption of rutile concentrate (gross weight), by uses, 1941–54¹

Year	Total consumption, short tons	Average estimated TiO ₂ , percent	Welding-rod coatings		Alloys and carbide		Ceramics		Miscellaneous	
			Short tons	Percent of total	Short tons	Percent of total	Short tons	Percent of total	Short tons	Percent of total
1941	6,361	94.1	5,461	85.9	² 709	11.1	172	2.7	³ 19	0.3
1942	10,616	93.7	8,857	83.4	1,652	15.6	92	.9	³ 15	.1
1943	17,634	93.3	12,358	70.1	5,221	29.6	21	.1	³ 34	.2
1944	14,813	93.4	10,747	72.6	4,014	27.1	20	.1	³ 32	.2
1945	9,791	93.4	7,813	79.9	1,923	19.6	34	.3	³ 21	.2
1946	7,134	93.5	5,990	84.0	1,035	14.5	75	1.0	³ 34	.5
1947	7,692	92.1	6,425	83.6	1,131	14.7	102	1.3	34	.4
1948	10,230	92.7	7,885	77.1	952	9.3	175	1.7	1,218	11.9
1949	9,662	92.8	6,399	66.2	660	6.8	143	1.5	2,460	25.5
1950	11,721	92.7	9,218	78.6	1,454	12.4	195	1.7	854	7.3
1951	17,227	93.0	11,708	68.1	2,939	17.0	265	1.5	⁴ 2,315	13.4
1952	18,317	94.7	11,418	62.3	2,997	16.4	281	1.5	⁴ 3,621	19.8
1953	20,019	94.4	10,476	52.3	2,394	12.0	317	1.6	⁴ 6,832	34.1
1954	20,663	94.0	8,817	42.7	2,069	10.0	372	1.8	⁴ 9,405	45.5
1955										
1956										
1957										

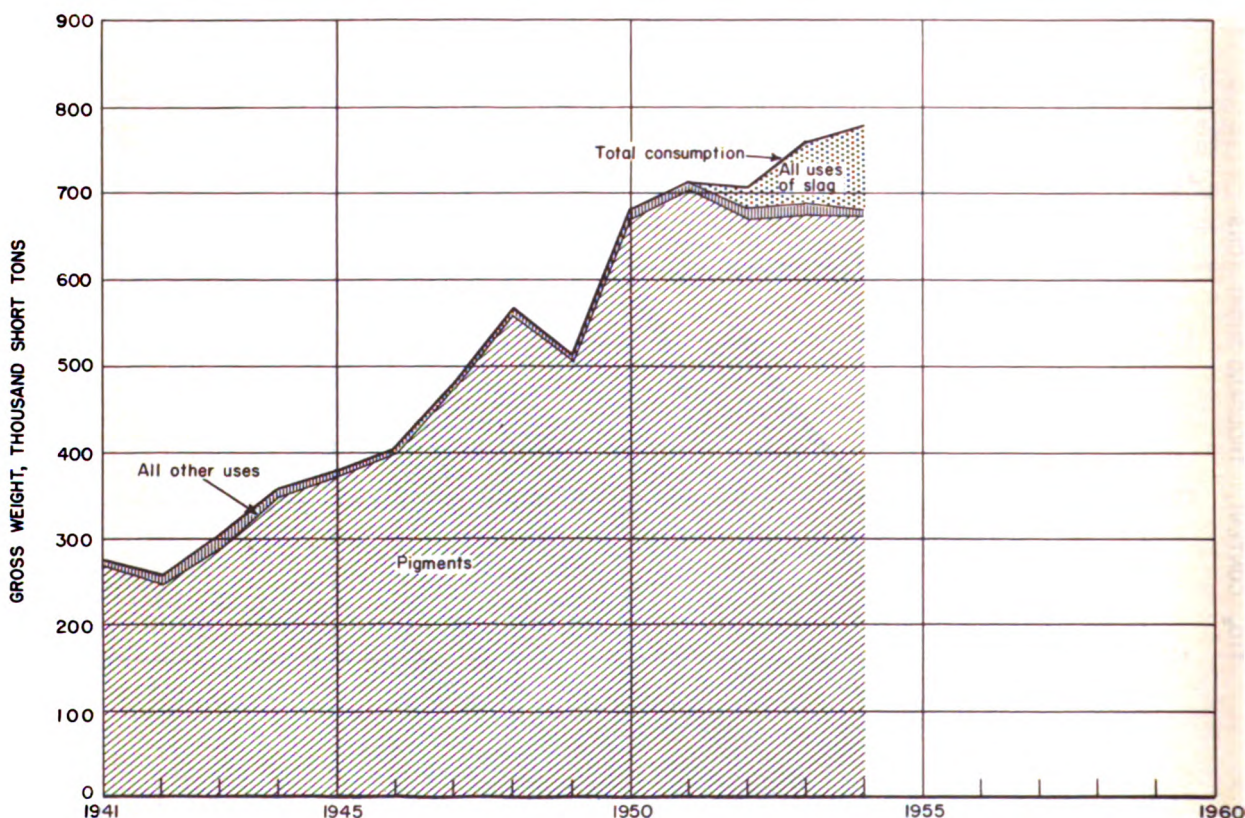
¹ Data not available before 1941.² Alloys only.³ Consists of rutile used in lamp electrode coatings and as a steel deoxidizer.⁴ Includes metal and fiberglass.

Figure 2.—United States Consumption of Ilmenite Concentrate, by Uses, 1941–54.

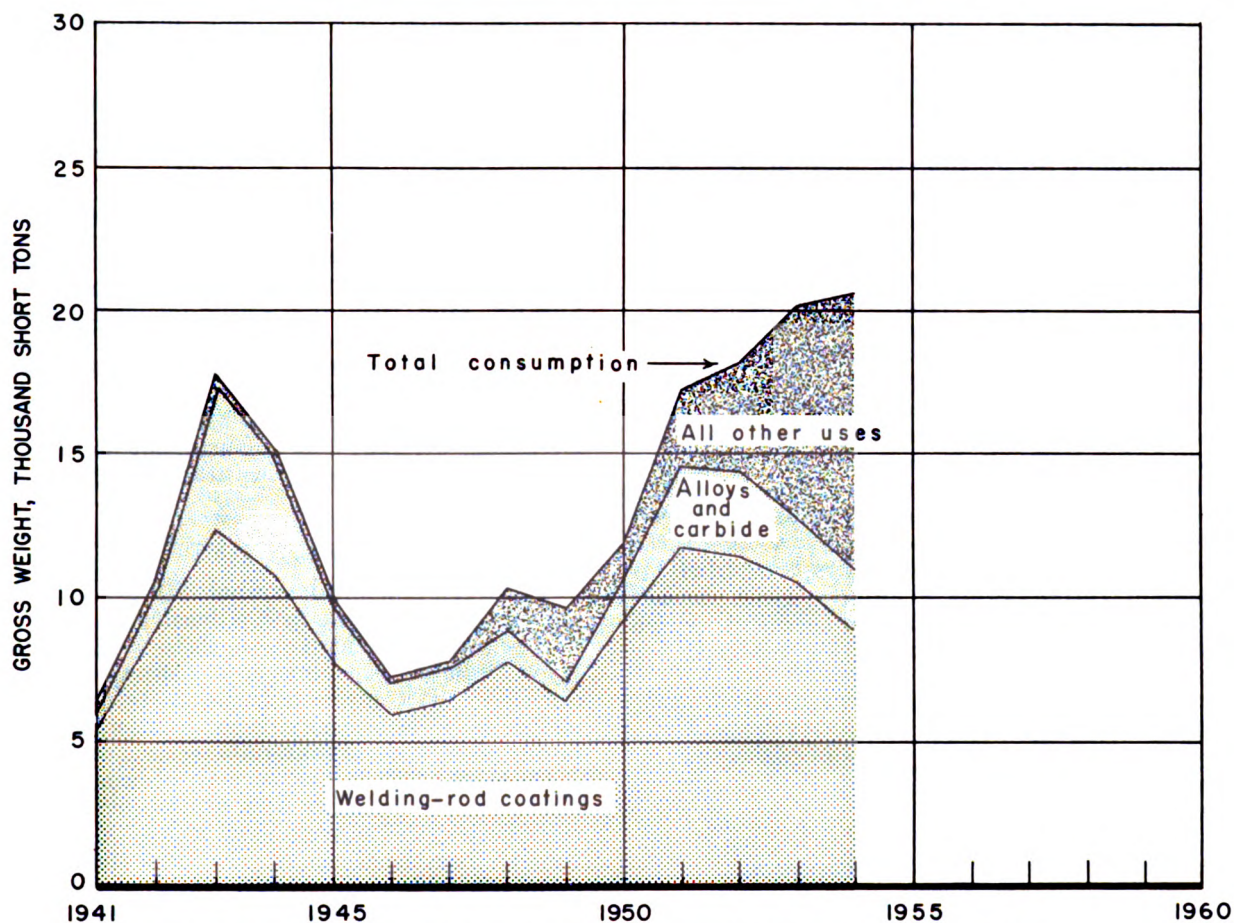


FIGURE 3.—United States Consumption of Rutil Concentrate, by Uses, 1941–54.

TABLE 5.—United States consumption of ilmenite and rutil concentrates and manufactured TiO_2 for the manufacture of welding-rod coatings, estimated titanium dioxide content, 1941–54¹

Year	Rutil		Ilmenite		Manufactured TiO_2		Total
	Short tons	Percent of total	Short tons	Percent of total	Short tons	Percent of total	
1941	5,133	74.8	30	0.4	1,700	24.8	6,863
1942	8,326	62.8	28	.2	4,900	37.0	13,254
1943	11,617	66.6	113	.6	5,700	32.7	17,430
1944	10,103	72.7	82	.6	3,900	27.7	14,085
1945	7,344	76.0	62	.6	2,258	23.4	9,664
1946	5,600	84.9	57	.9	938	14.2	6,595
1947	5,907	81.6	74	1.0	1,257	18.4	7,238
1948	7,289	83.8	72	.8	1,338	15.4	8,699
1949	5,904	83.5	85	1.2	1,082	15.3	7,071
1950	8,516	84.6	106	1.1	1,439	14.3	10,061
1951	10,834	85.1	130	1.0	1,770	13.9	12,734
1952	10,798	80.4	416	3.1	2,209	16.5	13,423
1953	9,812	79.2	584	4.7	1,986	16.1	12,382
1954	8,169	82.8	501	5.1	1,192	12.1	9,862
1955							
1956							
1957							

¹ Data not available before 1941.TABLE 6.—United States consumption of ilmenite and rutil concentrates and manufactured TiO_2 for the manufacture of alloys and carbide, estimated titanium dioxide content, 1941–54¹

Year	Rutil		Ilmenite		Manufactured TiO_2		Total
	Short tons	Percent of total	Short tons	Percent of total	Short tons	Percent of total	
1941	673	18.2	3,031	81.8	—	—	3,704
1942	1,526	20.6	5,899	79.4	—	—	7,425
1943	4,782	51.3	4,546	48.7	—	—	9,328
1944	3,683	45.6	4,401	54.4	—	—	8,084
1945	1,750	30.6	3,976	69.4	—	—	5,726
1946	966	32.3	2,025	67.7	—	—	2,991
1947	1,050	30.2	2,431	69.8	—	—	3,481
1948	889	25.5	2,591	74.5	—	—	3,480
1949	619	23.3	2,037	76.7	—	—	2,656
1950	1,366	26.4	3,803	73.6	—	—	5,169
1951	2,752	35.0	4,962	63.1	145	1.9	7,859
1952	2,858	32.1	5,763	64.8	277	3.1	8,898
1953	2,279	27.4	4,979	59.7	1,078	12.9	8,336
1954	1,987	37.7	2,779	52.7	503	9.6	5,269
1955							
1956							
1957							

¹ Data not available before 1941.

PRODUCTS: PROPERTIES AND USES

TITANIUM METAL

PRODUCTION

Although the production of titanium metal has required but a small percentage of the titanium minerals consumed in the United States, it has been essential, for most companies use rutile for this purpose. As a consequence, rutile has assumed a strategic importance out of proportion to its relatively small consumption. In 1955 it was not available in large enough quantities to support a greatly expanded titanium industry; therefore, any major expansion of the metal industry will probably be premised upon the use of ilmenite or titanium slag as a raw material. One company uses a mixed product classified as ilmenite, containing altered ilmenite, rutile, and leucoxene, as a source material for its metal. (See Preparation of Titanium Tetrachloride, chapter 5, for a further discussion of the possibility of substituting one material for another as a raw material for metal.)

Commercial production of titanium employs three major processing steps: (1) The source material is chlorinated, producing titanium tetrachloride; (2) the titanium tetrachloride is reduced by magnesium, forming a spongy mass of metallic crystals; and (3) the sponge is consolidated by melting. (See chapter 5.)

The Bureau of Mines is not at liberty to publish consumption figures for rutile used in the production of titanium metal, but about 2.0 to 2.4 pounds of rutile (or its equivalent in ilmenite or titanium slag) is required to produce 1 pound of titanium metal. Table 7 lists the production

TABLE 7.—*Production of titanium sponge, sponge in the revolving stockpile, and mill-product shipments, 1948-54, in short tons*

Year	Sponge produced	Sponge in revolving stockpile, Dec. 31	Mill products shipped
1948.....	¹ 10	.....	(²)
1949.....	¹ 25	.....	(²)
1950.....	¹ 75	.....	(²)
1951.....	495	.....	¹ 75
1952.....	1, 075	303	¹ 250
1953.....	2, 241	30	1, 114
1954.....	5, 370	2, 703	1, 299
1955.....			
1956.....			
1957.....			

¹ Estimate.

² Not available.

of titanium sponge and mill products. No figures are available for the output of mill products before 1953; however, most of the sponge produced from 1948 to 1952 probably went into some form of mill product. Mill products will not equal sponge used because of large scrap losses. In general, it takes about 2 pounds of sponge to produce 1 pound of mill product.

In 1952 the Government purchased 303 tons of titanium sponge for its revolving stockpile, but by June 1953 this stockpile was almost depleted by sales to semifabricators. The supply of titanium sponge again exceeded the demand in 1954, so the Government was obligated to purchase the excess production. As of December 31, 1954, the Government had 2,703 tons of titanium sponge in its revolving stockpile.

PHYSICAL PROPERTIES

Titanium (chemical symbol Ti) is a silvery gray metallic element with a density 57 percent that of steel. Its high strength-to-weight ratio below 1,000° F., corrosion resistance, and ductility have promoted the metal and its alloys to a potentially high position in the family of structural materials.

Pure titanium is not easy to obtain, as the metal combines readily with atmospheric gases, refractories, and other metals at high temperature to form hard alloys. In 1954 the purest metal available commercially was that produced by the iodide process, which consists of the decomposition of titanium iodide on a hot filament to yield titanium and iodine. (See chapter 5, Processing.) This high-purity metal (99.9 percent titanium) is soft and ductile, having a hardness number as low as 60 Brinell. Table 8 lists the physical properties of high-purity titanium.

Commercially pure metal (99.3 percent titanium) has historically been produced by the Kroll process, which is essentially the reduction of titanium tetrachloride by magnesium in an inert atmosphere. One plant in the United States and one plant in Great Britain are being constructed to employ the sodium reduction of titanium tetrachloride. Table 9 compares the physical properties of commercially pure titanium with those of some metals against which it may compete. From table 9 it may be seen that titanium has a comparatively high melting point that should make it useful as a structural metal at high temperatures. However, above 800° F. the strength of the metal drops rapidly, and above 1,300° F. titanium absorbs excessive oxygen and nitrogen, which embrittle the metal. Therefore, the metal is used mainly where temperatures do not exceed 800° F.

TABLE 8.—*Some physical properties of high-purity titanium*

Atomic number.....	22.
Atomic weight.....	47.90.
Atomic volume.....cc./gm.—atom..	10.6.
Density at 20° C. (68° F.) gm./cc.....	4.507.
lb./in. ³	0.163.
Hardness.....	80–100 Vickers.
Melting point.....° C.....	1,670 ± 20.
° F.....	3,040 ± 35.
Boiling point at 760 mm. Hg.....° C.....	3,260.
° F.....	5,900.
Linear coefficient of expansion 20°–300° C. (68°–572° F.) micro-inches per ° C.....	8.2.
Latent heat of fusion cal. per gm. (est.).....	100.
Latent heat of transformation cal. per gm.....	14.
Heat of combustion cal. per gm. to TiO ₂	4,700.
Electrical conductivity percent of copper.....	3.6.
Electrical resistivity at 25° C microhm-cm.....	54.98.
Superconductivity.....° K.....	Below 1.73.
Crystal structure:	
Below 882° C. (1,620° F.).....	Close-packed hexagonal (alpha).
Above 882° C. (1,620° F.).....	Body-centered cubic (beta).
Lattice constants:	
(Alpha).....	a = 2.9504 c = 4.6833.
(Beta).....	a = 3.3065.

SOURCE: American Society for Metals Committee on Titanium, Titanium and Titanium Alloys: Metal Progress, vol. 66, No. 1-A, July 15, 1954, pp. 80–89.

Recent tests, which reduced the possibility of contamination by refractories, indicate that the true melting point of pure titanium is probably closer to 1,660° ± 10° C. (3,020° ± 18° F.).

Titanium is only 57 percent as dense as steel, so that it can compete with other light metals in some uses where its high strength-weight ratio is important. The low thermal conductivity of titanium should be noted, as it occasions difficulty when the metal is machined. Its low electrical conductivity causes titanium to be used in some electrical applications where this feature is important. Another important property is its low coefficient of thermal expansion.

Titanium undergoes an allotropic change at 1,620° F. Below this temperature it has a close-packed hexagonal lattice, designated the alpha form. On being heated to above 1,620° F., titanium changes structure from close-packed hexagonal to body-centered cubic, which is designated as the beta form.

MECHANICAL PROPERTIES

The mechanical properties of a metal are usually defined on the basis of hardness, ultimate strength, yield strength, and elongation. These properties for titanium are extremely variable, depending upon the amount of impurities present. Table 10 compares the mechanical properties of high-purity titanium prepared by the iodide process and commercially pure titanium made by the Kroll process.

TABLE 9.—*Physical properties of titanium compared with some other metals*

Property	Commercially pure titanium	Aluminum 75-ST-6	Magnesium AZ-31A	Stainless steel AISI 302
Melting point.....° C.....	1,670 ± 20.....	476–638.....	565–632.....	1,400–1,420.
° F.....	3,040 ± 35.....	890–1,180.....	1,050–1,170.....	2,550–2,600.
Density:				
Gm./cc.....	4.5.....	2.80.....	1.78.....	7.93.
Lb./cu. in.....	0.1628.....	0.101.....	0.064.....	0.286.
Atomic number.....	22.....	13 (Al).....	12 (Mg).....	26 (Fe).
Atomic weight.....	47.90.....	26.97 (Al).....	24.32 (Mg).....	55.84 (Fe).
Crystal structure, type.....	H. C. P.....	F. C. C.....	H. C. P.....	F. C. C.
	Below 1,620° F. B. C. C. Above 1,620° F.			
Lattice constant.....	2.9505..... 4.6833	4.0413 (Al).....	3.2033 (Mg)..... 5.1998	
Thermal conductivity:				
Cal./cm. ² /sec./° C./cm.....	0.036.....	0.29.....	0.23.....	0.039.
B. t. u./ft. ² /hr./° F./in.....	105.....	845.....	672.....	113.
Thermal expansion:				
Cm./cm./° C.—20°/100° C.....	9.0 × 10 ⁻⁶	23.3 × 10 ⁻⁶	26.0 × 10 ⁻⁶	17.3 × 10 ⁻⁶ .
In./in./° F.—32°/212° F.....	5.0 × 10 ⁻⁶	12.9 × 10 ⁻⁶	14.5 × 10 ⁻⁶	9.6 × 10 ⁻⁶ .
Specific heat—cal./gm./° C. or B. t. u./lb./° F. at room temperature.....	0.130.....	0.23.....	0.25.....	0.12.
Electrical conductivity—percent of copper.....	3.1.....	30.0.....	18.5.....	2.3.
Electrical resistivity at 20° C.:				
Ohms/cir. mil ft.....	370.....	34.6.....	56.0.....	435.
Micro ohm-cm.....	61.....	5.75.....	9.3.....	72.
Tensile modulus of elasticity.....p. s. i.....	15.5 × 10 ⁶	10.4 × 10 ⁶	6.5 × 10 ⁶	28 × 10 ⁶ .
Torsional modulus of elasticity.....do.....	6.5 × 10 ⁶	3.8 × 10 ⁶	2.4 × 10 ⁶	12.5 × 10 ⁶ .
Poisson's ratio.....	0.34.....	0.33.....	0.35.....	0.3.

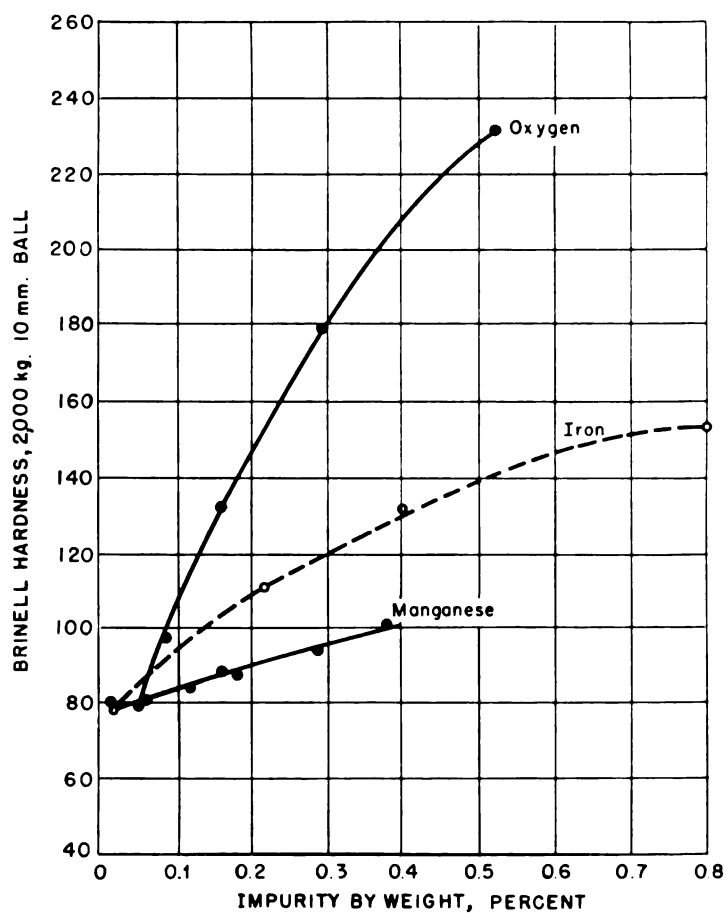


FIGURE 4.—Effect of Oxygen, Iron, and Manganese on Hardness of Electrolytically Refined Titanium.

TABLE 10.—*Comparative mechanical properties of high-purity and commercially pure titanium*

	High-purity	Commercially pure
Hardness, Brinell.....	55-95	120-200
Ultimate strength p. s. i.	35, 000-50, 000	50, 000-105, 000
Yield strength p. s. i.	15, 000-25, 000	40, 000- 95, 000
Elongation—percent in 2 inches.....	40-70	15-25

¹0.2 percent offset.

The impurities in commercially pure titanium harden and strengthen the metal by solid-solution mechanism, and as long as they are not excessive the resultant product has adequate strength and ductility. Figure 4 shows how some of these impurities affect the hardness of the metal. Work on the effect of nitrogen indicates that its curve roughly follows that of oxygen.

The commercially pure grade is subdivided into various strength levels, depending upon the purity of the product. Table 11 lists the grades produced by various companies in June 1955. The lower strength levels are used for purposes requiring maximum ductility, such as the manufacture of welded tubing from strip. The highest strength commercially pure metal is not so hard that it cannot be readily formed, machined, and welded.

Powder metallurgy may become a major means of fabricating titanium parts in the future, and the mechanical properties of parts fabricated by this means may be important. The Brush Development Co. produces fabricated parts in a grade of metal known as Brush Ti40 by both hot pressing and press forming. (See chapter 6, Fabrication.) The properties of press-formed Brush Ti40 are as follows: Ultimate strength, 64,200 pounds/in.²; 0.2 percent offset yield strength, 39,300 pounds/in.²; elongation in 0.850 in., 42.6 percent; and Charpy impact at 100° F., 29 to 36.

Commercially pure titanium is always in the alpha form at room temperature, since most of the impurities introduced in manufacturing processes are alpha stabilizers. Ease of fabrication of this material at room temperature is due partly to its being composed of only one phase. This grade also has no heat-treatment response, and hence no brittle two-phase areas can occur upon heating and cooling. For this reason, it is weldable, provided proper precautions are observed for inert-gas protection during welding.

The impact properties of commercially pure titanium vary from low to high values, depending on the purity and strength of the material. In the notched Charpy test at room temperature, high-purity material (about 65,000 p. s. i. ultimate strength) has absorbed as high as 150 foot-pounds energy; ordinary commercially pure material (70 to 90,000 p. s. i. ultimate strength) shows values ranging from 25 to 55 foot-pounds. These values are indicative of

TABLE 11.—*Nominal mechanical properties of annealed, commercially pure titanium produced by various companies, June 1955*

Manufacturer	Designation	Form	Minimum tensile strength, p. s. i.	Minimum yield strength, p. s. i.	Elongation, percent	Nominal impact	Bend radius	Hardness
Mallory Sharon Titanium Corp.	MST Grade III	Sheet	70, 000	50, 000	25	45	2T	R _a 53.
	do	do	85, 000	65, 000	23	-----	2T	R _a 59.
	do	do	100, 000	80, 000	20	-----	3T	R _a 60.
Rem-Cru Titanium, Inc.	A-40	-----	50, 000	40, 000	22	-----	-----	-----
	A-55	-----	65, 000	55, 000	18	-----	-----	-----
	A-70	-----	80, 000	70, 000	15	-----	-----	-----
Republic Steel Corp.	RS-40	Sheet	50, 000	40, 000	20	-----	-----	-----
	RS-55	do	65, 000	55, 000	20	25-40	1-2.5T	R _b 85-90.
	RS-70 and RS-70-A	do	80, 000	70, 000	18	20-35	1.5-3T	R _b 94-100.
Titanium Metals Corp. of America.	Ti-55A	do	55, 000	45, 000-65, 000	22	-----	2-2.5T	R _b 80-90.
	-----	Bar	55, 000	45, 000-65, 000	20	-----	-----	-----
	Ti-65A	Sheet	65, 000	55, 000-75, 000	20	-----	2-2.5T	R _a 30—(max.).
	-----	Bar	65, 000	50, 000-70, 000	20	-----	-----	-----
	Ti-75A	Sheet	80, 000	70, 000-95, 000	15	-----	2-2.5T	R _a 30—(max.).
	-----	-----	105, 000	-----	-----	-----	-----	-----
	-----	Bar	80, 000	65, 000-85, 000	20	-----	-----	-----
	Ti-100A	Sheet	100, 000	90, 000	15	-----	-----	R _a 30—(max.).

reasonable toughness. At higher temperatures, of course, the energy absorbable in the impact test becomes higher, and in general the transition from low to high impact values occurs between 100° and 300° F.

The fatigue properties of titanium are good, unnotched specimens having endurance limits in some instances almost as high as the yield strength. Even in the notched condition, titanium shows high endurance limits comparable with those of the stronger steels. The quality of the surface markedly affects the fatigue properties of titanium. Surface cold work decreases the fatigue strength, and a machined, polished surface gives the optimum values.

At room temperature annealed commercially pure titanium shows poor creep characteristics, but cold working greatly improves the creep behavior. Titanium alloys, however, have good creep properties. From this it is apparent that commercially pure metal in the full-annealed condition should not be used in structures where it will be permanently loaded at stresses close to the yield strength.

Titanium has poor high-temperature properties, as the ultimate and yield strengths drop rapidly above 800° F. Titanium can be exposed to temperatures up to 2,000° F. for short periods when strength is not the important consideration. In 1 experiment a titanium plate exposed to a nitrogen-free flame for 30 minutes at 2,000° F. regained its strength upon cooling. However, titanium probably will find most use between 400° to 800° F., that is, between the upper limit of aluminum and the lower limit of the true high-temperature alloys.

Titanium has very undesirable friction and wear characteristics. It is prone to seize during such operations as deep drawing, tube drawing, or wire drawing and has a high tendency to gall. Conventional lubricants do not remedy this situation because titanium surfaces have a very low ability to retain an oil film. This may be due to the presence of a stable oxide film, which prevents the formation of absorbed layers of the lubricant on the surface. Titanium itself has a high coefficient of friction; coupled with this is the fact that, when it rubs against another material, it tends to rub off onto this material, so that, subsequently, the two surfaces become titanium rubbing against titanium.

CHEMICAL PROPERTIES

In the periodic classification of the elements, titanium falls in group IV, subgroup A, along with zirconium, hafnium, and thorium. It has an atomic number of 22 and an atomic weight of 47.90 and is most frequently bi-, or tri-, or quadri-valent. It comes between beryllium and magnesium in the electromotive series and

should therefore be a very active metal. Actually, titanium exhibits great chemical activity only at elevated temperatures and is relatively inert at room temperature. For example, titanium does not react with pure oxygen below 250° F. but burns at 1,130° F. Above 950° F. the metal combines with the active gases of the atmosphere, forming a surface scale. At higher temperatures the gases diffuse into the lattice, forming interstitial compounds. This diffusion occurs with oxygen above 1,300° F., and ignition of the metal will take place in air at 2,200° F. The metal burns with a bright incandescence in a nitrogen atmosphere at above 1,500° F. Atmospheric nitrogen diffuses into the lattice at 1,500° F. but with a restricted depth of penetration.

At slightly above room temperature hydrogen is reversibly absorbed by the metal, forming a hydride. Hydrogen can only be added below 680° F., because above this temperature the gas is evolved and burns. Above 1,500° F. water vapor is decomposed on titanium to form the oxide and hydrogen, and at higher temperatures carbon dioxide is also decomposed.

Titanium tetrafluoride is formed by the direct action of fluorine gas on the metal above 70° F. The tetrachloride is formed at 660° F., the tetrabromide at 680° F., and the tetraiodide at 750° F. At very high temperatures these reactions are reversed.

The resistance of titanium to corrosive mediums is probably the result of a protective film of stable oxide, absorbed oxygen, or, in the case of sea water, a hypochloride layer. Air facilitates the formation and repair of this film, and hence the presence of air at the metal surface is frequently an important factor in corrosion behavior. The corrosion rates of titanium in mineral acids are known to be greatly decreased as a result of the presence of even low concentrations of such reagents as nitric acid or cupric or ferric ions. Furthermore, all of these passivating agents tend to change the electrode potential of titanium so as to put it near the noble end of the galvanic series.

Titanium is particularly resistant to sea water and marine atmospheres. Excellent results have been reported in such environments with respect to general corrosion, pitting, crevice corrosion, erosion, and stress corrosion cracking. Titanium exhibits excellent resistance to all concentrations of nitric acid and aqua regia; however, explosions have resulted in several experiments in which titanium alloys were immersed in red fuming nitric acid. At room temperature it has good resistance to sulfuric acid in concentrations up to 5 percent and to hydrochloric acid in concentrations up to 3 percent but corrodes rapidly in hydrofluoric acid.

Titanium is not attacked when exposed to ammonium hydroxide at room temperature. Dilute sodium and potassium hydroxides attack the metal slowly. Titanium can resist hot solutions of sodium hydroxide in moderate concentrations.

Moist chlorine gas and water saturated with chlorine gas have little effect upon the metal, and titanium can resist hot or cold chloride salts, except for a boiling solution of greater than 25 percent aluminum chloride. An important feature of titanium is that it is not greatly affected by solutions of cupric and ferric chlorides. Sodium and calcium hypochlorite corrode the metal slightly.

Titanium displays excellent resistance to most organic acids, including hot and cold acetic, lactic, citric, and stearic. It is virtually unaffected by boiling solutions of carbon tetrachloride, trichlorethylene, formaldehyde, and chloroform. Hot oxalic and trichloroacetic acids and boiling formic acid rapidly attack titanium.

In stress-corrosion tests titanium has held up well. Stress corrosion occurs when cracks in the protective oxide film offer points of attack for the reagent. Titanium showed no stress corrosion in 20 different reagents, but red fuming nitric acid rapidly developed cracks in the surface of the metal.

In galvanic corrosion tests titanium behaves somewhat similarly to stainless steel. The titanium metal itself does not usually corrode severely, but the corrosion of the other metal coupled with it may be increased. Magnesium in salt water and in normal urban atmospheres behaved the worst of the 11 metals tested in 1 experiment. Gas bubbles were evolved at the junction of the titanium and magnesium, although this action was somewhat decreased by using alloys of titanium rather than commercially pure metal. Zinc and iron showed high galvanic penetration, and even aluminum alloys corroded at an undesirable rate. Copper, brass, nickel, and nickel-base alloys showed very low galvanic corrosion when coupled with titanium. Under some circumstances titanium will become electronegative when coupled with aluminum and will slowly corrode.

TITANIUM-BASE ALLOYS

PROPERTIES

Titanium is alloyed with other elements to increase its strength and hence its strength-weight ratio.

Table 12 shows the commercial alloys on the market in 1955, with their nominal mechanical properties. It can be seen that the strengths are relatively high compared with that of commercially pure titanium but that the ductility (per-

cent elongation) is correspondingly lower, so that the highest strength alloys are relatively brittle. At present this lack of ductility distinctly limits the strength levels of these alloys, many of which are capable (through heat treatment) of higher strengths than are listed in table 12.

Alloying elements in titanium fall into two groups: Those that strengthen and stabilize the alpha or room-temperature form and those that strengthen the beta or high-temperature form. In the former category are oxygen, nitrogen, carbon, and aluminum, while iron, manganese, chromium, molybdenum, and vanadium fall in the latter group. Adding alpha stabilizers increases strength without changing the microstructure; that is, the alloy remains in the single-phase alpha form. When carbon, nitrogen, oxygen, or a combination of these elements is used for alloying titanium, the ductility falls rapidly as the strength is raised. For alloys of this type the highest workable tensile strength would be only slightly above 100,000 p. s. i.; further additions of these elements would render the alloy too brittle. Moreover, while gain is observed in room-temperature strength, high-temperature strength is not increased by additions of carbon, oxygen, or nitrogen.

To obtain increases in strength with less sacrifice of ductility, the alloys shown in table 12 were developed. Many of these alloys contain only beta-stabilizing alloying elements; in other words, the high-temperature or beta phase is strengthened, so that under most conditions the alloys contain both alpha and beta phases at room temperature. This structure accounts for the high strength of these alloys, which must all be heat-treated to yield desirable mechanical properties. In some instances the alloys contain both a beta-stabilizing element and an alpha-stabilizing element; examples of these are RS-130 and MST 3Al-5Cr. The addition of the alpha-stabilizing element increases the high-temperature oxidation resistance and helps to restrain the growth of beta grains at high temperature; hence, these alloys can be readily forged.

Except for aluminum, all the alloying elements used are heavier than titanium. Thus, as the alloy percentage increases, the density of the alloy increases; moreover, as stated before, the ductility also decreases, and ease of fabrication is also lost. Consequently, there are practical limits to the addition of alloying elements. There have been some instances, however, of alloy heats having both high strength and high ductility. There is evidence that if the oxygen, nitrogen, and carbon contents are kept low, the titanium alloys will have high ductility and can be fabricated more easily.

TABLE 12.—*Mechanical properties of annealed titanium-base alloys produced by various companies, June 1955*

Manufacturer	Designation	Form	Minimum tensile strength, p. s. i.	Minimum yield strength, p. s. i.	Elongation, per cent	Reduction in area, sq. in.	Bend radius	Hardness
Mallory Sharon Titanium Corp.	MST 3A1-5Cr	Bar	¹ 155,000	¹ 145,000	13	35		R _c 32.
	MST 4A1-4Mn	do.	¹ 150,000	¹ 140,000	14	35		R _c 32.
	MST 8Mn	Sheet	¹ 137,000	¹ 125,000	16		3T	R _c 35.
	MST 6A1-4V	Bar	¹ 150,000	¹ 140,000	10	30		R _c 30.
		Sheet	¹ 150,000	¹ 130,000	12		5T	
Rem-Cru Titanium, Inc.	C-130AM	Forging	140,000	130,000	10			
	A-110AT	Bar and sheet.	120,000	110,000	10			
	C-110M	do.	120,000	110,000	10			
	C-120AM	do.	130,000	120,000	10			R _c 36 (max.)
	C-120AV	do.	130,000	120,000	10			
Republic Steel Corp.	RS-110-A	Sheet	120,000	110,000	10		3-4T	R _c 28-34.
	RS-120	Bar	130,000	120,000	12			R _c 29-35.
	RS-130	do.	140,000	130,000	10			R _c 30-36.
Titanium Metals Corp. of America.	Ti-140A	Sheet	120,000	110,000	12		3.5T	R _c 30-34.
		Bar	130,000	115,000	15			
	Ti-155A	do.	135,000-145,000	130,000-135,000	10-12	25		
	Ti-6A1-4V	Sheet	130,000	120,000	10	15-25	4-5T	R _c 36 (max.)
		Bar	130,000	120,000	10	25		

¹ Typical rather than minimum property.

Most of the alloys shown in table 12 cannot be welded, because of an extremely brittle heat-affected zone which regains only slight ductility on heat treatment. Because of this, only the commercially pure metal had been employed for fusion welding until recently, when special alloys were designed for this purpose. One of these is an all-alpha alloy containing aluminum and tin. An all-alpha structure was purposely sought to avoid the brittle alpha-beta heat-affected zone in welding. The alloy contains tin in addition to aluminum, because tin increases the strength without loss in workability; an alloy containing over 8 percent aluminum is difficult to fabricate. There is some experimental evidence that some alpha-beta alloys of low alloy content would be readily weldable and yet high in strength, although this field must be more fully investigated.

An experimental alloy that shows some promise for high-temperature applications contains 36 percent aluminum. Its major drawback is difficulty in fabrication. In general, aluminum is an excellent alloying element for titanium, since it improves the strength-weight ratio and is low in cost.

The impact properties of titanium alloys are generally inferior to those of the commercially pure metal, with room temperature notched Charpy values ranging from about 15 to 40 foot-pounds. In most instances fairly sharp energy-absorption transitions from low to high impact values occur between 100° and 300° F. Purity of original sponge, that is, low contami-

nation, raises the impact values generally and lowers the transition temperature.

Titanium alloys have good fatigue properties; in some instances their endurance limits are nearly as high as their yield strengths. Even in the notched condition, titanium and its alloys have high endurance limits. It is suspected that the impurity content of the original sponge would have some effect on these properties, as it does on ductility and impact. The impurities present in titanium scrap and master alloys added in melting probably have a significant effect on the properties of the final titanium alloy.

Titanium alloys drop in strength considerably faster than commercially pure metal above 800° F. The all-alpha material apparently retains its strength at high temperatures somewhat better than the mixed alpha-beta alloys. Titanium and its alloys are good structurally at temperatures up to about 800° F.; above this temperature stainless steel is superior if strength is of primary importance.

USES OF TITANIUM METAL AND ITS ALLOYS

The properties of titanium metal that recommend its use in many applications include its low density, strength, and corrosion resistance. Factors that at present limit its application include the high cost, difficulty of fabrication, and excessive reactivity at high temperatures.

Although titanium metal has been suggested for many applications, its major use in 1954 was

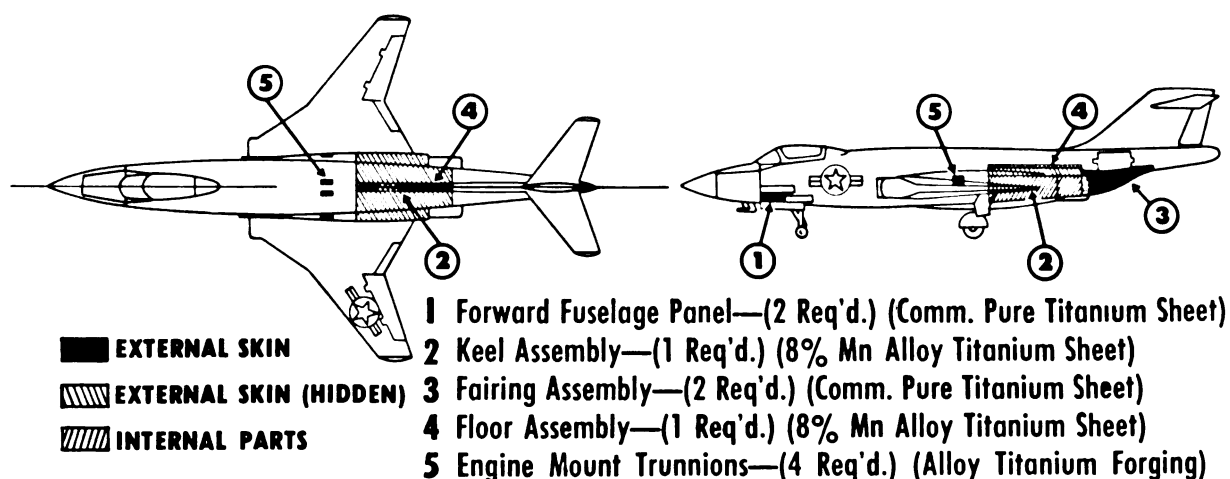


FIGURE 5.—Use of Titanium in the McDonnell F-101A "Voodoo."
(Courtesy of Rem-Cru Titanium, Inc.)

for military purposes. Present and potential applications of titanium metal and its alloys are as follows:

AIRCRAFT AND JET ENGINES

The largest military market for titanium metal is in the aircraft industry for airframes and powerplants. Titanium is destined for use by the airframe producers in firewalls, skin, landing-gear components, hydraulic tubing, shrouds, oil and fuel tanks, nacelle structures, fasteners, and engine supports. The major use of titanium in aircraft powerplants is in compressor disks and blades; compressor housings, retaining rings, and fasteners have also been fabricated. Replacement of other metals by titanium can be found in airplanes, such as the supersonic Douglas X-3, where titanium is substituted for aluminum parts that are exposed to engine heat or heated aerodynamically. Commercially pure titanium has been used in North American's jet airplanes for shroud assemblies, cable shrouds, ammunition tracts, and flap rubbing strips; titanium-alloy material has been used for fuselage frames and bulkheads. In 1955 titanium was being used in major components of the J-57 gas-turbine engine, the B-47 and B-52 jet bombers, and the F-100, F-101, and F-102 jet fighters. Figure 5 illustrates the use of titanium in the McDonnell F-101 "Voodoo."

Producers of civilian aircraft are also interested in the use of titanium in many of the same applications where the metal can be advantageously employed in military craft. The wider use of jet-powered, high-speed commercial transport planes will provide a ready market for titanium alloys. Douglas Aircraft was the first to use titanium in a commercial airliner. In its DC-7 titanium was substituted for stainless steel in the engine nacelles and

firewalls. In 1955 titanium was being used in the DC-7, the DC-8, and the 707 civilian transport.

ORDNANCE

The use of titanium in ordnance applications that called for lightweight, good-strength, corrosion-resistant metal was investigated by the Army. Titanium has been used in place of steel in the prototype production of mortar-baseplates and in the manufacture of flash suppressors for artillery use. The resistance of some titanium alloys to ballistic penetration is considered greater than that of conventional armorplate of equal weight. Titanium replaced brass in certain primer cups because of its greater resistance to chemical action. The fast-burning quality of titanium powder has been considered for use in rockets, and it has also been used in the detonating fuse of explosives. Lowering the cost of titanium should lead to possible additional uses of the metal by the Army, such as in bridges, cylinders for compressed gases, airstrip landing mats, field-gun mount trails, and anti-aircraft-gun outriggers.

MARINE EQUIPMENT

Titanium metal, with its outstanding resistance to sea water and marine environments, together with its light weight and fatigue resistance, was studied by the Navy for use in salt-water valves for valve seats and disk trims, tubing for condenser systems and heat exchangers, wet exhaust valves for submarine diesel engines, and turbine blades for low-temperature steam turbines. Additional naval uses of titanium based on lower cost of the metal may be found in the manufacture of salt-water pumpshafts, small outboard propeller shafts, snorkel tubes, and hull material for small craft, such as PT boats.

CHEMICAL EQUIPMENT

Because of its excellent corrosion resistance, titanium metal appears to have promising applications in the chemical industry, such as handling of hypochlorite solutions (commercial bleaching compounds); chlorine dioxide, particularly in the paper-pulp industry; and metallic chlorides, particularly ferric and cupric, and organic acids.

OTHER USES

The characteristics of titanium suggest numerous other uses. These include surgical instruments, orthopedic appliances, portable machine tools, sporting equipment, food handling and processing equipment, valve parts, X-ray tube targets, and textile machinery.

PIGMENTS

PROPERTIES

Because of the superior hiding power of manufactured titanium dioxide the most important use of titanium minerals is in the manufacture of pigments. In 1954, 95 percent of the total titanium dioxide content of the ilmenite and rutile ores consumed in the United States was used in pigment manufacture. Titanium dioxide is sold as "straight" or unextended pigments and as "composite" or extended pigments (in combination with calcium sulfate). There are no universally accepted standard grades, incorporating such factors as specific gravity, hiding power, tinting strength, particle size, and chemical inactivity.

"Rutile" and "anatase" are the two crystal modifications of titanium dioxide manufactured for pigment use. The anatase-crystal type was manufactured exclusively until 1941, when rutile-type pigments were placed on the market. The rutile-type pigments, both extended and unextended, have replaced the older varieties to a large extent because of their superior

opacity and resistance to chalking and fading. The hiding power, tinting strength, specific gravity, and refractive index of some commonly used white pigments are compared in table 13.

The relatively high hiding power and tinting strength of titanium dioxide pigments are perhaps the primary factors in the rapid adoption of titanium dioxide in the manufacture of paints, varnishes, and lacquers. Specific gravity, which affects the rate of settling, is also important in some applications.

USES

Since its introduction in 1916 manufactured titanium dioxide has found a steady market in the production of paints, varnishes, and lacquers; paper; floor coverings; rubber; coated fabrics and textiles; and miscellaneous other products. The percentage distribution of shipments of titanium dioxide pigments from 1935 to 1954 is shown in table 14 and plotted in figure 6.

The high opacity and chemical inertness of titanium dioxide permit it to be used in almost every variety of plastic material, resin, and molding powder, except urea and thiourea mixtures. Its resistance to erosion by lactic and acetic acid makes it particularly desirable for use in plastics of the celluloid type, which are often treated with acetic acid, and casein, which usually contains residual lactic acid. When used as a rubber pigment, a small quantity of titanium dioxide gives a high degree of whitening, with the result that most of the desirable natural properties of the rubber can be retained.

Because of its high index of refraction, low specific gravity, fine particle size, and chemical stability, titanium dioxide fulfills the requirements for a filler and opacifier in the manufacture of paper and textiles. As an opacifier in paper the pigment is about 10 times as effective as the ordinary fillers and improves the

TABLE 13.—*Specific gravity, hiding power, tinting strength, and refractive index of some common white pigments*

	Specific gravity	Hiding power, ¹ sq. ft. per lb.	Tinting strength ²	Average refractive indices
Titanium dioxide (rutile).....	4. 20	147	1, 600	2. 72
Titanium dioxide (anatase).....	3. 90	115	1, 250	2. 52
Zinc sulfide.....	4. 00	58	640	2. 37
Titanium dioxide-calcium sulfate (rutile).....	3. 25	57	600	1. 98
Lithopone (regular).....	4. 30	27	280	1. 84
Zinc oxide.....	5. 65-5. 78	20	210	1. 99-2. 02
Basic carbonate white lead.....	6. 80	15	120-150	1. 94-2. 09
Basic sulfate white lead.....	6. 40	13	120-160	1. 93

¹ Hiding power = (tinting strength [black] × 0.1) + 3.

² As determined by Reynolds constant-volume method—ultramarine blue.

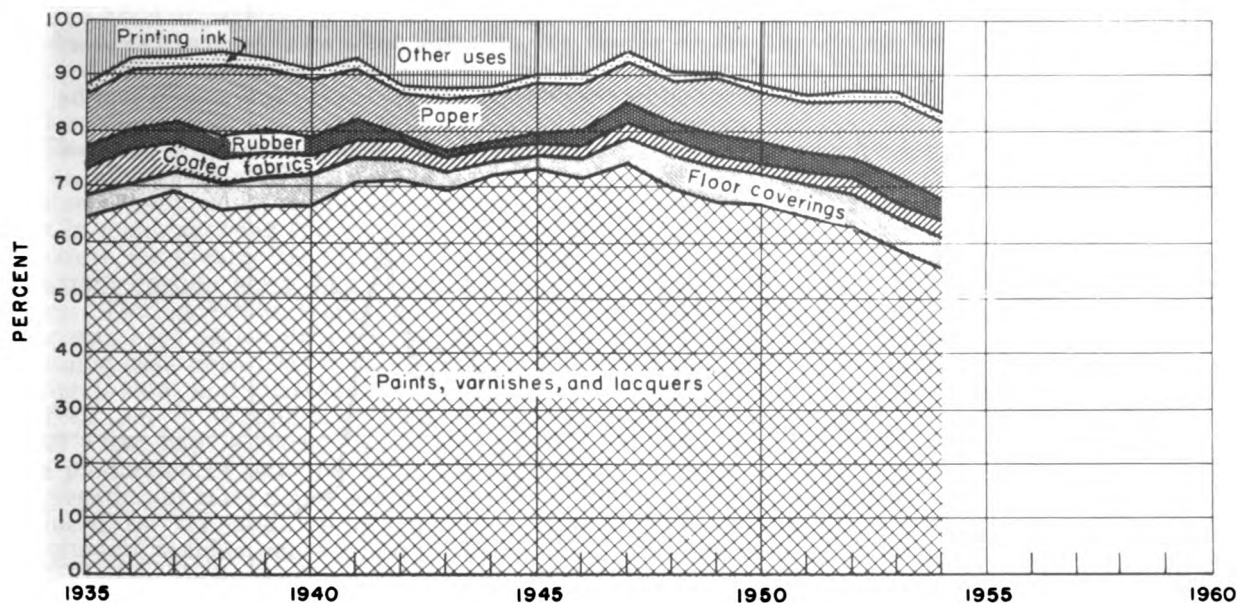


FIGURE 6.—Distribution of Titanium-Pigment Shipments in the United States, by Uses, 1935-54 (Based on TiO_2 Content).

TABLE 14.—Distribution of titanium-pigment shipments in the United States, by uses, 1935-54, in percent¹

(Titanium dioxide content)

Year	Paints, varnishes, and lacquers	Floor coverings (linoleum and felt-base)	Coated fabrics and textiles (oilcloth, shade-cloth, etc.)	Rubber	Paper	Printing ink	Other	Total
1935	64.8	3.5	4.8	4.2	9.4	2.0	11.3	100
1936	66.7	3.8	6.2	3.6	10.6	2.1	7.0	100
1937	69.1	3.7	4.9	3.9	9.8	1.8	6.8	100
1938	65.9	4.7	4.3	4.2	13.1	2.0	5.8	100
1939	66.5	5.3	4.1	4.3	11.1	1.9	6.8	100
1940	66.7	5.3	3.3	3.7	10.4	1.7	8.9	100
1941	70.8	4.4	3.3	3.5	9.2	1.7	7.1	100
1942	71.3	3.6	3.5	1.0	7.6	1.4	11.6	100
1943	69.5	3.1	2.6	1.1	9.5	1.7	12.5	100
1944	71.9	2.7	2.4	1.0	8.6	1.4	12.0	100
1945	73.4	2.5	2.0	1.6	9.3	1.4	9.8	100
1946	71.9	3.1	2.3	2.8	8.6	1.5	9.8	100
1947	74.3	4.7	2.6	3.4	7.8	1.5	5.7	100
1948	69.9	5.9	2.7	3.2	7.4	1.4	9.5	100
1949	67.5	5.8	2.1	3.9	9.6	1.4	9.7	100
1950	66.9	5.2	2.0	3.9	9.1	1.4	11.5	100
1951	64.9	5.7	2.1	3.4	8.9	1.8	13.2	100
1952	62.9	5.6	2.9	3.6	10.4	1.6	13.0	100
1953	58.8	5.4	2.6	4.5	14.1	1.6	13.0	100
1954	55.4	5.2	3.2	4.0	14.1	1.6	16.5	100
1955								
1956								
1957								

¹ Data not available before 1935.

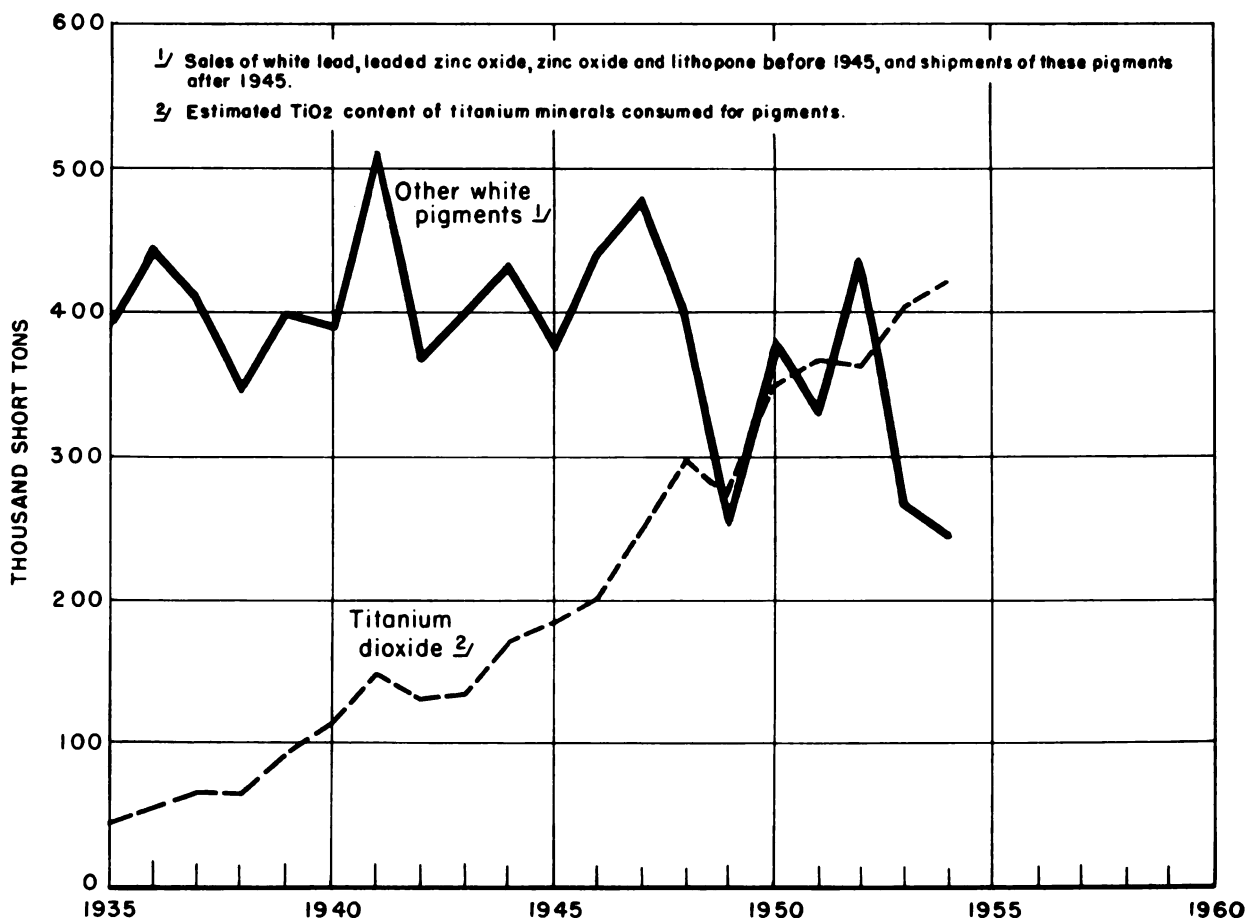


FIGURE 7.—Titanium Dioxide Content of Minerals Consumed in Making Pigments and Estimated Consumption of Other White Pigments, 1935-54.

color, brightness, and printing surface. Its properties also favor its use as a delustrant in the production of rayon.

Chemical inactivity is another important characteristic of the compound. It may be used with virtually all types of reactive vehicles; it is not discolored by most gases that may be present in the atmosphere, such as hydrogen sulfide and ammonia; it does not discolor on exposure to sunlight; and it is not affected by extremes of temperature. Titanium dioxide is resistant to alkaline, acid, and saline solutions and may be used as the pigment in chemical-resistant paints of many types. It is compatible with other white and colored pigments and may be used in combination with many of them.

CONSUMPTION

The production of titanium dioxide pigments in the United States has increased steadily since 1920, when the annual production was reported to be 100 tons. Growth and present magnitude of the industry are illustrated in figure 7, which gives an indication of the apparent consumption of titanium pigments as

compared with that of other white pigments. Contrasted with the rather steep increase in the consumption of titanium pigments is the gradual decrease in the total consumption of other white pigments (white lead, leaded zinc oxide, zinc oxide, and lithopone). The decline in the use of these other white pigments has not been as rapid as might be expected, because they are used in mixtures with titanium dioxide in various paints. Titanium-pigment production can be estimated by multiplying the estimated TiO_2 content of titanium minerals used for the production of pigments by a recovery figure of 80 to 90 percent.

NON-TITANIUM-BASE ALLOYS AND CARBIDE

Use of titanium as an alloying element is limited. In general, it is used in minor amounts (less than 1 percent) to refine grain size, to restrain segregation, and to act as a deoxidizer.

STEEL

Titanium is used in the steel industry in the form of master alloys, which are identified

on the basis of carbon content as high-carbon, medium-carbon, and low-carbon ferrotitanium. An iron-silicon-titanium alloy is also available for adding silicon and titanium simultaneously to low-alloy steels.

Titanium may have a dual role when used as an alloy with steel. As a deoxidizer it is not as economical or as effective as aluminum, but in manufacturing certain grades of steel it provides for greater cleanliness. In addition, titanium dioxide has a flux action on various slags. During World War II low-grade ilmenite was used as a substitute for fluorspar in thinning basic open-hearth slags. However, its action is slow, and fluorspar is preferred.

Titanium is occasionally used in rimmed steel when high surface quality is desired in the production of slabs for strip and tinplate. Segregation of carbon and sulfur in rail steel is reduced by the addition of titanium. This results in a tougher, more uniform rail.

Titanium finds application in cast steels through its property of reducing the grain size. With low-alloy cast steel the requirements are higher, and it is used where the higher cost is economically justified. The addition of 0.04 percent titanium to medium-manganese steel, used in railroad castings, refines the grain and improves the yield ratio and ductility.

In stainless steels titanium equal to four times the quantity of carbon present is added to form titanium carbide. If titanium is not added, the chromium precipitates as chromium carbide at the grain boundary areas when the metal is heated. Titanium has a greater affinity for carbon than does chromium and combines with all the available carbon in the melt, thus allowing the chromium to remain in solution whenever the metal is heated.

OTHER ALLOYS

Titanium has been applied to a limited extent in copper alloys and aluminum and its alloys. In these applications the titanium refines the grain and removes gases. Additions to aluminum and copper are usually made in the form of master alloys. Additions of less than 5 percent titanium to copper alloys results in age hardening, which increases the stiffness and strength of forged bars. As a result of decreased grain size, aluminum castings show improvement in tensile strength and resistance to leakage.

Nickel-base alloys and nickel-manganese-titanium alloys have also been developed, although they are not widely used. An addition of 0.5 percent titanium to molybdenum alloys increases hot hardness.

CARBIDE

Titanium carbide is one of a family of carbides characterized by their high hardness

and wear and abrasion resistance. They have been developed mainly for cutting tools and other tools in which wear resistance is essential. The most common member of this family is tungsten carbide, which has been used for tools for many years. In most instances carbides far outperform high-speed steel. In some special tools a mixture of tungsten carbide and other carbides is used, one of the most prevalent being titanium carbide. Tungsten carbide-titanium carbide mixtures or a double carbide of tungsten and titanium is used in tools operating at relatively high temperature; the titanium carbide imparts a lower coefficient of friction, oxidation resistance, and resistance to cratering wear.

For work at 1,800° F. or above, titanium carbide is used for hot-cutting tools, hot-working tools and dies, crucibles for molten glass, and quenching jigs for thin strip steel. Experiments have been conducted using titanium carbide for rotary parts in the high-temperature end of gas turbines, such as turbine blades. When used here it forms one of the class of so-called cermets or ceramics. Its high oxidation resistance, high thermal conductivity, and comparatively low density make it promising for this field.

Of the refractory carbides titanium carbide is the least dense (density=5.5 grams per cubic centimeter) and has the third highest melting point, 5,680° F. Although its strength at room temperature is relatively unimpressive, it has high tensile strength at elevated temperatures, somewhat over that of the best superalloys; moreover, its density is lower than that of these alloys. As an example, a cermet containing 54 percent titanium carbide and 40 percent nickel has a strength of 41,000 p. s. i. at 1,800° F. Its oxidation resistance is outstanding and becomes even more so when small amounts of other carbides (such as tantalum and columbium (niobium)) are added to it.

WELDING-ROD COATINGS

The major use of rutile in the past has been as an ingredient of welding-rod coatings. In these coatings rutile usually forms a large portion of the flux with ferromanganese and other alloys and fluxing constituents, such as silicates. The purpose of the flux is to flow over the molten metal and seal out the air, which would contaminate the weld. Rutile in the welding-rod coating imparts better flowing and covering power than any other material. The high rutile content also results in a flat surface deposit of excellent appearance and a solid but easily removed slag.

Rutile is the most commonly used source of TiO₂ for welding-rod coatings; however, ilmenite, a mixture of ilmenite and rutile, manufactured

TiO₂, a mixture of rutile and manufactured TiO₂, titanium slag, and manufactured potassium and sodium titanate are also used for this purpose.

Although the consumption of rutile has increased in recent years, as shown in table 5, the amount consumed in welding-rod coatings during 1953 and 1954 has decreased slightly. The increased total consumption of rutile is due to the increased interest in the production of titanium metal and fiberglass, which currently require rutile.

During 1946-51 there was a steady decline in the stocks of rutile in the United States. As a result of this shortage, some of the manufacturers turned to the use of ilmenite as a partial substitute for rutile. The proportion of titanium-material-coated electrodes using the various forms of titanium is shown in table 15. Comparison of the data for 1952, 1953, and 1954 with the previous 6 years shows that the portion of the titanium-material-coated electrodes using ilmenite increased nearly 3 to 5 times in these 3 years over the previous 6 years.

The data in table 15 are misleading, in that they give greater relative importance to the consumption of ilmenite than is justified by the actual consumption of ilmenite for welding-rod coatings. For example, in 1954, 29 percent of the welding rods were coated with ilmenite, although only 501 tons of ilmenite (based on the TiO₂ content) was used for this purpose, whereas 8,169 tons of rutile was needed to coat about 46 percent of the coated welding rods.

The relative importance of these various titaniferous materials for coating welding rods may be better gaged by dividing the pounds of

material consumed (based on TiO₂ content) by the total tonnage of titanium-coated welding rods. These ratios are given in table 16 and graphed in figure 8.

TABLE 16.—*Titaniferous material (TiO₂ content) consumed per ton of titanium-coated welding rod, 1941-54, in pounds*

Year	Ilmenite	Rutile	Manu- factured TiO ₂	Total TiO ₂
1941.....	0.4	68	22	90
1942.....	.2	51	31	82
1943.....	.5	48	23	72
1944.....	.4	53	20	73
1945.....	.5	55	17	73
1946.....	.9	84	14	99
1947.....	1.0	77	16	94
1948.....	.8	76	14	91
1949.....	1.1	77	14	92
1950.....	1.1	91	15	107
1951.....	.9	75	12	88
1952.....	3.1	81	17	101
1953.....	4.7	80	16	101
1954.....	5.4	88	13	106
1955.....				
1956.....				
1957.....				

The whole picture is not revealed by any of these tables, because the quantity of potassium and sodium titanate consumed for welding-rod coatings is not available, and the tonnage of titanium slag consumed for coatings cannot be released because the figure would reveal individual company operations. However, the tonnage of slag and titanates used for this purpose is relatively small.

Figure 8 shows that the pounds of rutile consumed per ton of titanium-coated welding rod was much lower during World War II (1941-45) than in later years, whereas the amount of manufactured TiO₂ consumed per ton was much higher during World War II than in the succeeding years. The average per ton during 1941-45 was 55 pounds of rutile, 23 pounds of manufactured TiO₂, and 0.4 pound of ilmenite. The average per ton in 1946-54 was 81 pounds of rutile, 15 pounds of manufactured TiO₂, and 2.1 pounds of ilmenite. These figures would be somewhat greater if the calculations had been based upon the gross weight rather than upon the estimated TiO₂ content of the various titaniferous materials. The averages seem to indicate that manufactured TiO₂ was used partly as a substitute for rutile during World War II. A comparison of the total TiO₂ consumed in welding-rod coating during these same periods shows that an average of 78 pounds per ton was used in 1941-45, while 98 pounds per ton was used in 1946-54. This would indicate that not only does substitution occur in periods of short supply but that less titaniferous material is used per ton of coated welding rod. Another interpretation of these figures is that different

TABLE 15.—*Total tonnage of titanium-material-coated electrodes accounted for by each type of coating*

Year	Production of titanium-coated welding rods, short tons	Percent			
		Ilmenite	Rutile	Manufactured TiO ₂	Rutile plus TiO ₂
1941.....	152,000	2	48	45	5
1942.....	321,000	<1	40	52	7
1943.....	481,000	<1	38	52	9
1944.....	382,000	1	39	49	11
1945.....	267,000	2	42	46	10
1946.....	133,000	6	53	33	8
1947.....	153,000	6	54	33	7
1948.....	188,000	6	56	32	6
1949.....	154,000	6+	54	33	6+
1950.....	188,000	6	55	32	7
1951.....	288,000	6	61	15	18
1952.....	266,000	17	48	18	17
1953 ¹	246,000	29	40	20	11
1954 ¹	184,000	29	46	14	10
1955.....					
1956.....					
1957.....					

¹ In addition less than 1 percent was coated with titanium slag in 1953 and about 1 percent in 1954.

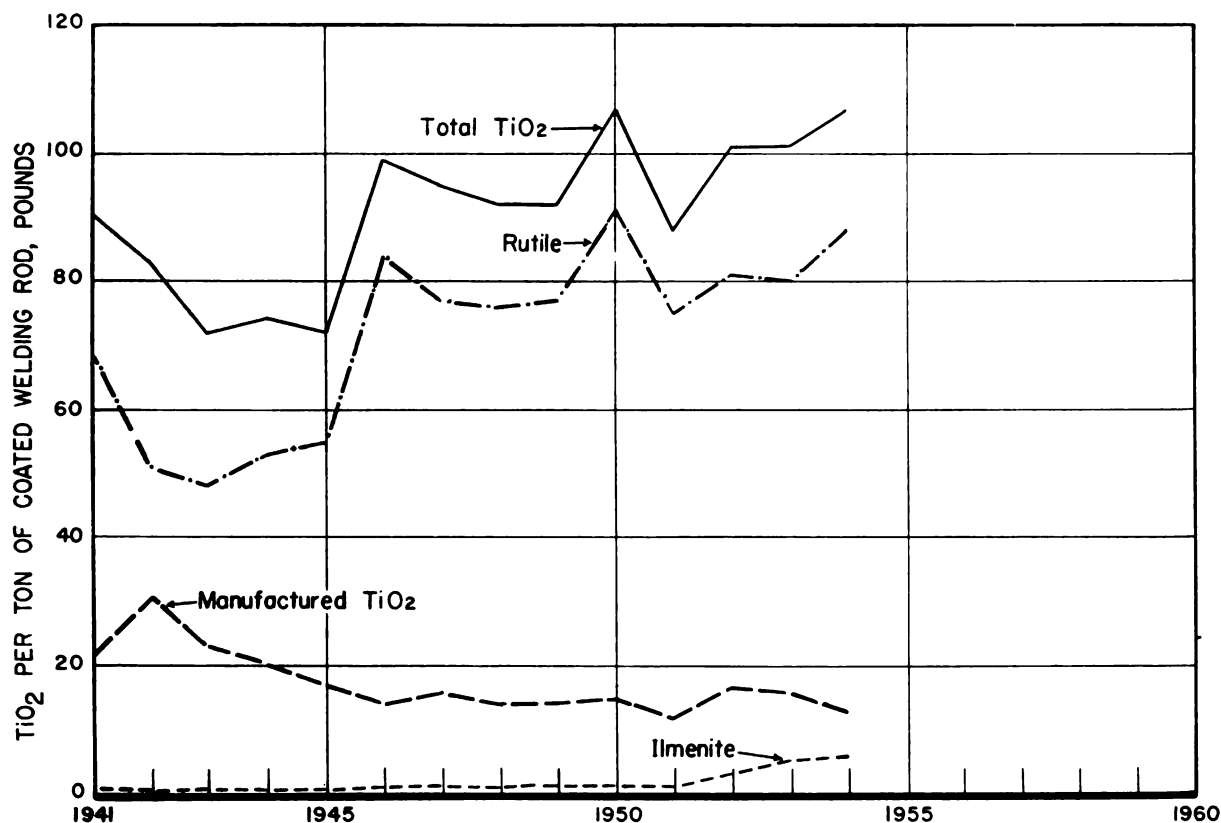


FIGURE 8.—Titaniferous Material (TiO₂ Content) Consumed Per Ton of Titanium-Coated Welding Rod, 1941-54.

types of coatings were developed in the postwar years and that more TiO₂ per ton was needed for these new coatings.

It should be noted in figure 8 that the pounds of ilmenite per ton of welding rod increased markedly in 1951 after having previously remained fairly constant.

In spite of the fact that manufactured TiO₂, ilmenite, and titanium slag may be substituted for rutile in some welding-rod coatings the manufacturers state that these materials cannot be substituted in all of the coatings. Manufactured TiO₂ has too fine a particle size for some uses, and ilmenite and slag do not have the desired chemical properties.

MISCELLANEOUS USES

There are many minor uses of titanium, primarily in the form of titanium dioxide. Two of the most important minor uses are in the fiberglass and ceramic industries.

The primary application of titanium in the ceramics industry is as a constituent of porcelain enamels. Only since 1945 has utilization of titanium dioxide as the major opacifying agent in these enamels had commercial impor-

tance. Enamels containing titania have high covering power, brilliance, and hardness and show good scratch, abrasion, and impact resistance. The superior opacifying power of these enamels has resulted in a weight reduction of almost 50 percent in the coating. The use of titanium dioxide as a major opacifying agent in porcelain enamels is finding increased use for stoves, refrigerators, signs, reflectors, architectural products, sanitary ware, and hollow ware. Before these enamels were introduced, special types or combinations were required, depending upon the specific end use. The need for many of these types has now been eliminated. Applications of these enamels show improved adherence and require a lower maturing temperature. They may be applied directly on sheet steel, aluminum, and other metal bases.

In general, it is apparent that the use of titania in porcelain enamels will result in a continuously increasing demand for titanium dioxide. However, in 1954 the consumption of manufactured titanium dioxide for ceramic applications was only 986 short tons.

A recent application in which titanium is assuming increasing importance is in the fiberglass industry, where it is incorporated to

shrink the fibers. Rutile is usually employed for this purpose, although manufactured titanium dioxide or ilmenite may be used.

Ceramic titanates are finding an increasingly important place in the electronic industry. Barium titanate and solid solutions of barium and strontium titanates have exceptionally high dielectric constants and show remarkable piezoelectric effects. The biggest field of application is in capacitors for television sets. They are also used for phonograph pickups, microphones, and high-frequency sound generators. Titanate ceramic radiators for production of ultrasonic energy may find new uses in application of ultrasonic radiation to chemical processes.

Titanium tetrachloride was used during World Wars I and II for producing smoke clouds for concealing and spotting purposes. This chemical also is used for skywriting for advertising purposes.

Titanium compounds have been used experimentally as fire-retardant agents for fabrics. Titanyl chloride-antimony trichloride complex, found to be effective in providing flame retard-

ance, has been applied to many types of cellulose fabrics.

The alkyl titanates derived from the action of titanium tetrachloride on alcohols were reported to be very effective waterproofing agents. These compounds can impart a water-repellant finish to such diverse materials as paper, cotton, wool, rayons, nylon, silk, felt, and wood. Potential industrial applications depend on the commercial availability of these compounds at reasonable cost. Titanium esters, acylates, and chelates were reportedly produced in 1954 in pilot quantities. These titanium organic compounds were stated to be suitable for surface-active agents, adhesives, polymers, and metal protection.

Clear, transparent rutile gems that exhibit brilliance superior to that of diamonds are manufactured from titanium dioxide. Rutile gems are relatively soft when compared with diamonds but have an index of refraction of 2.7 compared with 2.41 for diamonds.

The present and potential uses of titanium and titanium compounds have been outlined in figure 9.

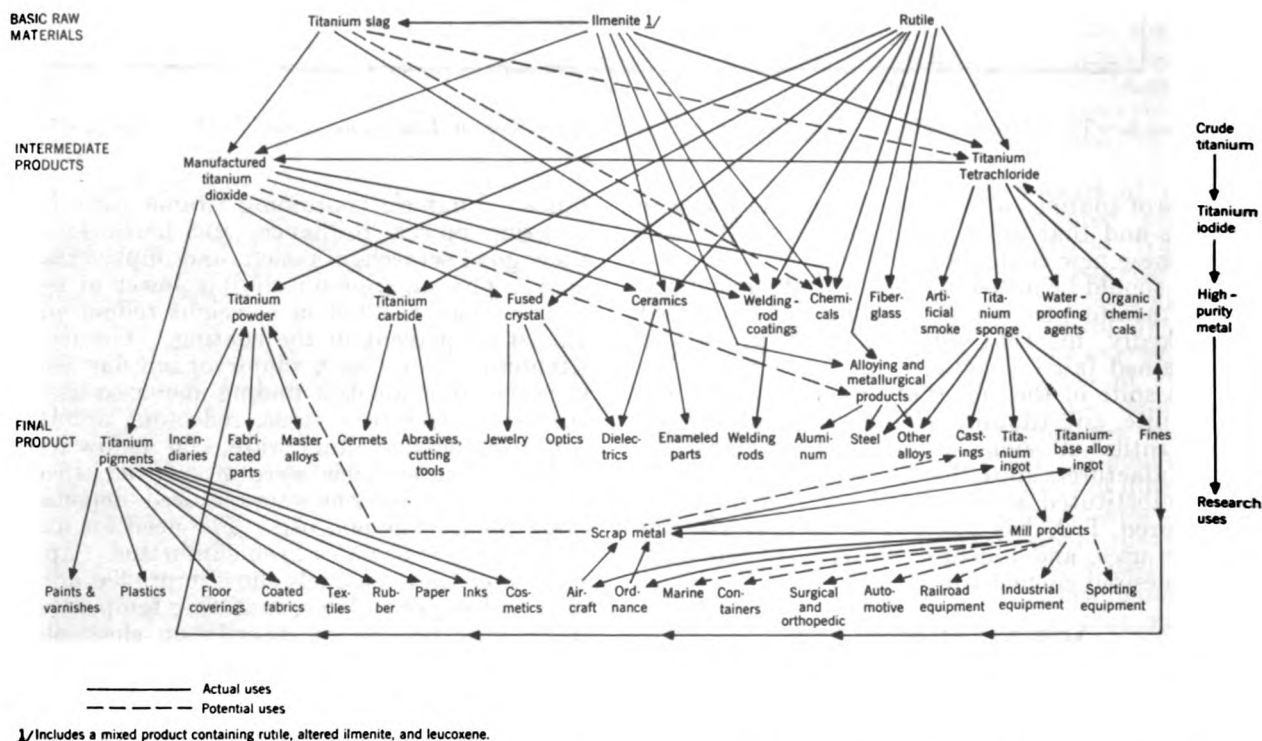


FIGURE 9.—Basic Raw Materials, Intermediate Products, and Final Products Containing Titanium.

CHAPTER 2. MINERALOGY AND GEOLOGY OF TITANIUM DEPOSITS ³

PREFACE TO CHAPTERS 2, 3, AND 4

Chapters 2, 3, and the section on prospecting in chapter 4 were prepared by the Federal Geological Survey in January 1954 and revised in December 1955. The information in these three chapters is based entirely on published or open-file material.

The word "ore" in chapters 2 and 3 is used to describe titaniferous mineral aggregates that could be profitably mined under the economic conditions of 1955. The word "ore" is enclosed in quotation marks where necessary to refer to the writings of authors who have used the term in a less restricted sense.

Dr. Olof H. Ödman of the Swedish Geological Survey courteously supplied information and provided references on titaniferous deposits in Sweden. Miss Anna Poire and Miss Taisia Stadnichenko of the Federal Geological Survey very kindly translated several reports in Russian. Mrs. Barbara B. Knapp aided by translating a Swedish report.

PRINCIPAL TITANIUM-BEARING MINERALS IN DEPOSITS

Titanium ranks ninth in abundance of the elements in both the outer 10 miles of the crust of the earth and in the igneous rocks of the earth. It comprises 0.62 percent by weight of the crust and 0.48 percent by weight of the igneous rocks of the earth. Some of the more common titanium and titanium-bearing minerals are listed in table 17.

The most common titaniferous minerals are anatase, ilmenite, leucoxene, and rutile. In addition, a few deposits contain large amounts of less common minerals; a large perovskite deposit in Colorado recently has attracted considerable attention, brookite occurs in one deposit in Arkansas, and sphene may be used as an ore in the Kola Peninsula of Russia. Magnetite, an ore of iron, usually contains some titanium and commonly occurs with ilmenite.

ANATASE (TiO₂)

Anatase (formerly called octahedrite) crystallizes in the tetragonal system, is brown, and in

³ By Robert Lawthers, formerly geologist, Federal Geological Survey

TABLE 17.—Principal titanium and titanium-bearing minerals

Mineral	Formula	TiO ₂ , percent	Specific gravity
Oxides:			
Anatase.....	TiO ₂	98.4-99.8.....	3.90
Brookite.....	TiO ₂	94.1-98.8.....	4.06-4.20
Maghemite.....	Fe ₂ O ₃	1.37.....	5.18
Magnetite.....	FeFe ₂ O ₄	Up to 7.57.....	
Rutile.....	TiO ₂	89.5-99.0.....	4.21-4.25
Ilmenorutile.....	Fe ₂ (Nb, Ta) ₂ Th ₁₋₂ O ₃	41.2-54.6.....	4.64-5.59
Tantalum rutile.....	do.....	45.7-71.2.....	4.91-5.30
Ulvöspinel.....	Fe ₂ TiO ₄	21.4.....	
Titanates:			
Geikielite.....	MgTiO ₃	63.8-67.7.....	3.97-4.11
Ilmenite.....	FeTiO ₃	48.6-57.3.....	4.68-4.79
Perovskite.....	CaTiO ₃	58.6-58.8.....	3.98-4.04
Cerian perovskite (kno- pite).....	(Ca, Ce)TiO ₃	47.6-56.4.....	4.21-4.88
Niobian perovskite.....	(Ca, Nb)TiO ₃	38.7-50.9.....	4.13-4.26
Pyrophanite.....	MnTiO ₃	50.5-51.8.....	4.54-4.63
Titanosilicates:			
Sphene.....	CaTiSiO ₅	34.4-44.9.....	3.4-3.56
Silicates:			
Amphibole.....	Complex.....	Variable up to 2.0.....	
Biotite.....	do.....	Variable up to 4.7.....	
Garnet (var. schorlomite).....	Ca ₂ (Fe, Ti) ₂ (Si, Ti) ₂ O ₇	Variable up to 22.1.....	
Olivine.....	(Mg, Fe) ₂ SiO ₄	Variable up to 6.1.....	
Pyroxene (var. titanian augite).....	Complex.....	Variable up to 9.0.....	

the natural state contains 98.4 to 99.8 percent TiO₂. It has the same chemical composition as rutile and brookite but different properties and crystal habit.

"ARIZONITE"

Although "arizonite" has been cited frequently as one of the titanium-bearing minerals, recent work has shed considerable doubt on its existence as a definite mineral species. Examination of X-ray photographs by Overholt, Vaux, and Rodda (67) ⁴ indicated that "arizonite" is an impure mixture of hematite, ilmenite, anatase, and rutile, as this combination of compounds accounted for all the lines in the X-ray pattern. This evidence was considered sufficient to cast doubt on the existence of "arizonite" as a separate mineral. The authors believed that partial destruction of the ilmenite crystal structure by oxidation results in an

⁴ Italicized figures in parentheses refer to items in the bibliography (ch. 14). Page references apply to the items cited and not to this circular.

excess of ferric iron over that normal for ilmenite and produces the mineral assemblage listed above.

BROOKITE (TiO_2)

Brookite, like anatase and rutile, consists solely of titanium dioxide but differs from them by having different physical properties. It crystallizes in the orthorhombic system, is brown to yellowish and reddish-brown, and in the natural state contains 94.1 to 98.8 percent TiO_2 .

ILMENITE (FeTiO_3)

Ilmenite, one of the more common titaniferous minerals, is iron-black and crystallizes in the hexagonal system. Although it consists theoretically of 52.66 percent TiO_2 and 47.34 percent FeO , it may contain, at ordinary temperatures, minor amounts of magnesium and manganese and as much as 6 percent by weight of Fe_2O_3 . Higher amounts of Fe_2O_3 are often recorded in analyses of supposedly pure ilmenite but are presumably due to intergrowths of magnetite or hematite. The excess of titanium dioxide shown in some analyses may be caused by admixed rutile, which may form intimate mixtures with ilmenite. In polished sections ilmenite often shows intergrowths and regularly arranged exsolution lamellae of hematite, maghemite, magnetite, rutile, and spinel. The analyses of ilmenite in table 18 were selected from Palache, Berman, and Frondel (68, p. 537) to emphasize the considerable variation in composition.

LEUCOXENE

Some writers have used leucoxene as a distinct mineral name; actually it is fine-grained rutile or anatase, or mixtures of these with amorphous material. This alteration product, usually

containing over 60 percent TiO_2 , occurs with sphene, ilmenite, perovskite, titanium magnetite, or other titanium minerals. Most investigators agree that leucoxene is a mixture, but they do not agree upon the exact composition of the crystalline material or upon the relative amount of any associated amorphous material. Because of the differing opinions, it would seem best to follow the advice given by Allen (57), who says:

Leucoxene should be retained as a petrographic term for the alteration product in which titania occurs in rocks, but it must not be used as a mineral name implying a definite mineral species.

MAGNETITE (FeFe_2O_4)

Magnetite, a magnetic ferrous and ferric oxide of iron, crystallizes in the isometric system, is black to brownish black, and is opaque. It commonly occurs with titaniferous minerals, especially ilmenite, and may contain as much as 7.5 percent TiO_2 at ordinary temperatures. Analyses showing a higher titanium content probably were made of magnetite that contained exsolved material, possibly ilmenite. Magnetite forms intergrowths with chlorite, hematite, hercynite, ilmenite, muscovite, olivine, pyrophanite, and rutile. Substitution of chromium and vanadium for the ferric iron in the magnetite lattice is possible in limited amounts.

PEROVSKITE (CaTiO_3)

Perovskite crystallizes in the orthorhombic or monoclinic system but occurs in pseudo-isometric, black to red or yellow cubes or in massive granular masses. It is essentially calcium-titanium oxide and in the natural state contains 38.7 to 58.8 percent TiO_2 (Palache, Berman, and Frondel, 68, p. 732). Niobium (columbium) commonly substitutes for the titanium, and cerium and other rare earths may substitute for the calcium.

RUTILE (TiO_2)

Rutile occurs as reddish-brown to red crystals of tetragonal habit or in granular masses. It is essentially pure TiO_2 , although varieties rich in ferric iron, niobium, and tantalum are common. Analyses of rutile from Palache, Berman, and Frondel (68, p. 557) indicate that a ferrian variety contains up to about 11 percent of ferric iron in substitution (?) for titanium; a tantalum variety has as much as 36.0 percent Ta_2O_5 substituting for titanium; and columbian varieties (also called ilmenorutile) have substituting for the titanium as much as 32.2 percent Nb_2O_5 in one specimen and 23.5 percent Nb_2O_5 and 23.5 percent Ta_2O_5 in another.

TABLE 18.—Selected analyses of ilmenite

Constituents	1	2	3	4	5	6	7
TiO_2	52.66	52.73	51.32	54.20	48.64	50.02	56.43
Fe_2O_3			2.10	2.58	5.57	6.03	7.16
FeO	47.34	45.83	42.38	42.85	41.76	40.87	33.91
MgO		1.25			.88	1.72	2.10
MnO			3.37		1.10	.43	
Remainder.....			.36		1.66	1.08	
Total.....	100.00	99.81	99.53	99.63	99.61	100.20	99.60
Sp. gr.....	4.79		4.71			4.68	

1. Calculated FeTiO_3 .
2. Mount Ruwenzori, Belgian Congo.
3. Ambatofotsikely, Madagascar. Remainder, SiO_2 0.16, U_3O_8 0.20.
4. Chibinsky Tundra, Siberia.
5. Sasso di Chiesa, Val Malenco, Lombardy. Remainder, SiO_2 0.60, Al_2O_3 0.91, H_2O 0.15.
6. Val Devero, Ossola, Italy. Remainder, SiO_2 0.76, Al_2O_3 0.20, H_2O 0.12.
7. Same as col. 7.

SOURCE: Palache, Charles, Berman, Harry, and Frondel, Clifford (68).

SPHENE (CaTiSiO_5)

Sphene crystallizes in the monoclinic system and usually occurs as wedge-shaped or flattened brown, gray, yellow, green, rose-red, or black crystals or massive, compact masses. Analyses show 34.4 to 44.9 percent TiO_2 , 22.2 to 29.6 percent CaO , 29.1 to 34.6 percent SiO_2 , zero to 7.84 percent Fe_2O_3 , and minor amounts of FeO , MgO , MnO , or Al_2O_3 .

ULVÖSPINEL (Fe_2TiO_4)

Ulvöspinel, one of the spinel group of minerals, crystallizes in the isometric system and contains theoretically 21.4 percent TiO_2 . It is opaque and approximately as magnetic as magnetite (69, p. 687); other properties have not been described. It generally occurs in rocks that have no free hematite and contain an excess of ferrous over ferric iron. Ulvöspinel is found normally in magnetite as extremely small lamellae that are generally not observable unless the rock is examined in polished section with a magnification greater than 500 times. Unless an investigator has excellent equipment and is very careful in his polished-section work, he may overlook the ulvöspinel lamellae in magnetite and conclude that the ulvöspinel-bearing parts of the rock are only homogeneous magnetite.

Ulvöspinel was first described as an artificial mineral, and unknown in the natural state until an occurrence at Södra Ulvön, Sweden, was described by Mogensen (65). Ramdohr (69) recently has discussed many natural occurrences of the mineral and emphasized that it may be more common than previously realized. He also pointed out some of the problems that arise when deposits containing ulvöspinel are studied or commercially utilized.

MINERALOGY OF COMMON TITANIFEROUS AGGREGATES

The natural occurring titaniferous aggregates consist of titanium-bearing minerals and gangue, often intergrown with each other. The titanium-bearing deposits may be classed as primary, those found in bedrock, and secondary, those derived from the primary deposits by processes of weathering.

MINERALS IN PRIMARY DEPOSITS**ILMENITE-BEARING AGGREGATES**

In primary deposits the occurrence of ilmenite ranges from aggregates of pure ilmenite and silicate gangue to fine-grained mixtures of ilmenite, other iron oxides, and silicate minerals.

ASSEMBLAGES CONTAINING COARSE GRAINS OF ILMENITE OR ILMENITE AND MAGNETITE

Deposits containing large, separate grains of ilmenite and magnetite that are free from inclusions are not common. These deposits, if large enough, have economic significance, as the minerals from them generally can be beneficiated to produce marketable concentrates of ilmenite. The Yadkin Valley deposit, Caldwell County, N. C., contains separate grains of ilmenite that average less than 0.5 mm. and rarely exceed 1 mm.; magnetite is virtually lacking. Analyses of untreated ore showed a maximum of 41 percent TiO_2 (Singewald, 71, p. 85).

The occurrences near Tahawus are characteristic of the better New York deposits containing coarse-grained ilmenite and magnetite. The individual grains of ilmenite and magnetite at the National Lead Co. McIntyre deposit average 1 to 3 mm. in diameter. Commonly the subhedral ilmenite is embayed by anhedral magnetite. Intergrowths are apparently rare within ilmenite; but small intergrowths of ilmenite within magnetite are common, especially in the ores associated with anorthosite. These intergrowths in magnetite occur as small discontinuous plates and small "flecklike intergrowths" of ilmenite, both parallel to the octahedral planes of the magnetite and as small, irregular concentrations of ilmenite between magnetite grains (Stephenson, 72, pp. 412-416). Calculations based on Stephenson's observations of polished sections indicate an average of 46.7 percent magnetite and 39.8 percent ilmenite. Analyses of this rich ore indicate 20.7 to 24.7 percent TiO_2 and 46.6 to 53.4 percent Fe (Balsley, 58, p. 115).

ASSEMBLAGES CONTAINING ILMENITE AND HEMATITE

Assemblages containing ilmenite with included laths of hematite have commercial importance in some deposits. At Allard Lake, Quebec, one of the largest of these deposits, the ore occurs as dense, black, coarse-grained ilmenite in thick, tabular, well-formed crystals containing about 15 to 20 percent of included hematite in oriented, discontinuous, microscopic blades. The larger of these inclusions may contain smaller blades of included ilmenite, which also may contain still smaller blades of hematite. Analyses indicate that the ore contains as much as 36 percent TiO_2 and 43 percent iron (Hammond, 60, p. 120; 61, p. 644).

Ilmenite-hematite ore at St. Urbain, Quebec, consists of $\frac{1}{8}$ - to $\frac{1}{4}$ -inch grains of ilmenite having about 20 percent of hematite as intergrown lamellae about 0.2 mm. wide. These lamellae are essentially parallel within a given grain of ilmenite; their length greatly exceeds their width.

ASSEMBLAGES CONTAINING FINE-GRAINED ILMENITE AND MAGNETITE

Ilmenite and magnetite in many assemblages are either so fine-grained or so intergrown with each other that ore-dressing techniques cannot be used for extracting high-purity ilmenite concentrates. Consequently, utilization of such aggregates will necessitate chemical or pyrometallurgical techniques for recovering both the iron and titanium.

Coarse intergrowths of ilmenite in magnetite are common in many titaniferous magnetite deposits in North Carolina. In one deposit, the magnetite grains contain coarse, platelike intergrowths of ilmenite that are spaced 0.2 to 0.5 mm. apart, average 0.1 mm. in width and 2 mm. in length, and have a maximum length of 4 mm. (Singewald, 71, p. 88). Inclusions of ilmenite in magnetite from Lake and Cook Counties, Minn., range from submicroscopic to a maximum length of 2 to 3 mm. Material from Iron Mine Hill, R. I., and Taberg, Sweden, consists of magnetite, with numerous microscopic inclusions of ilmenite. At Taberg ilmenite occurs only as lamellae 0.01 to 0.05 mm. long and 0.1 to 0.2 micron thick, within 0.2- to 1-mm. grains of titanomagnetite; chemical analyses show 15.3 percent TiO_2 , 36.7 percent FeO , and 32.4 percent Fe_2O_3 (Hjelmqvist, 62).

Titaniferous material from the Bushveld complex, Transvaal Province, South Africa, contains mixtures of ilmenite, magnetite, and maghemite (a nonmagnetic ferric oxide with physical properties and crystal structure similar to magnetite) and averages 11.7 to 24.1 percent TiO_2 . The ilmenite occurs as laths 5 to 6 mm. long and 1 mm. wide, interstitial to other minerals, as individual grains with a cross section as large as 5 by 13 mm., and as inclusions that average 5 by 18 microns within magnetite and maghemite. The amount of ilmenite in large grains is not large enough to permit profitable mechanical beneficiation of this material.

NELSONITE

Nelsonite, a rock containing ilmenite or rutile or both, accompanied by apatite and possibly magnetite or subordinate silicate minerals, is mined in Amherst and Nelson Counties, Va. Individual nelsonite bodies have grain diameters of 1 to 3 mm. and contain 10 to 69.7 percent TiO_2 (Watson and Taber, 73, pp. 102, 120, 140).

CHROMIUM AND VANADIUM IN ILMENITE-BEARING AGGREGATES

Mineral assemblages containing ilmenite and magnetite may contain as much as 1.5 percent V_2O_5 and 2.4 percent Cr_2O_3 . Detailed mineralogical work on ilmenite and magnetite from various types of deposits shows that the chromium and vanadium are associated with magnetite more commonly than with ilmenite. Mineralogically this association is to be ex-

pected, as chromium and vanadium are absorbed more easily into the molecular structure of magnetite than that of ilmenite.

RUTILE-BEARING AGGREGATES

The occurrence of rutile is not always the same as that of ilmenite. At St. Urbain, Quebec, rutile constitutes about 6 percent of a deposit of ilmenite and rutile. Individual crystals and clusters of rutile grains average about 0.6 mm. in diameter.

Rutile in nelsonite of Amherst and Nelson Counties, Va., occurs as grains 1 to 2 mm. in diameter and in places constitutes as much as 75 to 80 percent of the deposit.

In deposits where rutile is the principal economic mineral, grains of rutile generally range in size from 0.5 to 10 mm. and constitute 4 to 5 percent of the deposit. At Magnet Cove, Ark., rutile in feldspar-carbonate veins has the following occurrences: Single acicular crystals averaging 0.1 mm. in diameter; nests of these crystals; compact acicular rutile masses ranging from less than 0.1 to 1 mm. in diameter; and granular rutile veins and veinlets ranging from 0.1 mm. to 5 cm. in width.

ASSEMBLAGES CONTAINING BROOKITE, PEROVSKITE, OR SPHENE

Although brookite, perovskite, and sphene occur commonly as accessory minerals in other assemblages, in a few places they occur in large enough concentrations to warrant attention. Brookite grains in the Christy deposit at Magnet Cove, Ark., average less than 0.5 mm. in diameter and attain a maximum diameter of 6 or 7 mm. At Iron Hill, Gunnison County, Colo., perovskite occurs as 1-mm. grains within magnetite.

MINERALS IN SECONDARY DEPOSITS

The titanium minerals that occur in secondary deposits have either separated out of a source rock during disintegration of the rock by weathering processes or are new minerals formed by these weathering processes.

TITANIFEROUS MINERALS IN SAND DEPOSITS

In sand deposits ilmenite and rutile are the commonest titaniferous minerals. These are usually accompanied by various amounts of leucoxene or other titaniferous alteration products.

In commercial practice all iron-bearing titanium minerals of sands are lumped under the heading of "ilmenite," even though other titaniferous minerals also may be present. Sand with an unusually high content of titanium is commonly described in the literature as containing "arizonite," although it is now believed that "arizonite" is not a separate mineral. Probably any titaniferous sand concentrate that

contains 55 to 70 percent TiO_2 , is a fine-grained mixture of ilmenite, leucoxene, rutile, anatase, and various iron oxides. Sand with a high content of titanium generally has much rutile or leucoxene, whereas that with a lower content of titanium may have much unaltered ilmenite.

Buried deposits of old beach sands also contain titaniferous minerals, although the degree of alteration of the titanium minerals may be more marked than in the modern beach deposits.

TITANIFEROUS MINERALS IN RESIDUAL DEPOSITS

The titanium minerals in residual deposits are those that resist chemical weathering and may include ilmenite, rutile, brookite, and leucoxene. The minerals may be embedded in a loose, porous, friable aggregate of weathered bedrock material, or they may be included within blocks of resistant material, such as quartz.

Clay derived from basalt and ferromagnesian rocks may contain weathered grains of ilmenite embedded in a matrix of clay minerals, such as montmorillonite, kaolinite, and halloysite, accompanied by hydrated-iron oxides and colloidal material.

Leucoxene and ilmenite occur in bauxite from Arkansas that averages about 2.12 percent TiO_2 .

MINERALOGICAL FACTORS THAT AFFECT UTILIZATION OF DEPOSITS

Utilization of titaniferous deposits depends on the size of the minerals and the content of titanium in these minerals. Assemblages most favorable for commercial development contain distinct grains of ilmenite, preferably at least 1 mm. in diameter and free from inclusions. Less favorable assemblages are those in which: (1) The titanium minerals are extremely fine grained, as in some leucoxene-bearing ores; (2) the titanium minerals occur as small intergrowths within nontitaniferous minerals; or (3) the titanium is within the molecular structure of a generally nontitaniferous mineral.

Another factor that affects utilization is the change in physical character of titaniferous aggregates that accompanies changes in the amount of silicate gangue within various parts of a deposit. For example, at Tahawus, N. Y., the ilmenite-magnetite ratio is greater in lean ore (containing over 30 percent silicate minerals) than in rich, massive ore (containing 10 to 30 percent silicate minerals). However, experiments have shown that the greatest recovery of ilmenite is from the richer ores, probably because these ores contain larger ilmenite grains and because less of the ilmenite occurs as inclusions within magnetite. Another example of difference in grain size and number of inclusions is in the Iron Mountain deposit in the Laramie

Range, Wyo. Massive titaniferous aggregates in this deposit are free from silicates and contain distinct grains of pure magnetite and ilmenite. Aggregates with over 5 percent silicate minerals also contain distinct ilmenite and magnetite grains, but the magnetite contains abundant exsolution lamellae of ilmenite ranging from microscopic to macroscopic size.

Variations in chemical composition of ore minerals generally accompany a change in the amounts of associated silicate gangue. Although this relationship has been noticed in a few places, it is often overlooked because adequate chemical analyses are lacking. Newhouse and Hagner (66, p. 14), in discussing the Iron Mountain, Wyo., deposit, suggest that ilmenite in ore accompanied by large volumes of silicates "contains a higher percent of iron relative to titanium * * * than it does in the massive ore." Study of ore at Tahawus, N. Y., shows that the nonmagnetic concentrate of rich ore contains 12 to 14.5 percent TiO_2 , whereas that from lean ore has only 7 to 12 percent TiO_2 (Balsley, 58, p. 114).

The presence of ulvöspinel in potential ores can introduce serious problems for utilization. Ulvöspinel contains as much as 21.4 percent TiO_2 , yet is so finely intergrown with magnetite that the 2 minerals cannot be mechanically separated. Deposits that contain appreciable amounts of titanium may be worthless if the titanium occurs mostly as ulvöspinel. Titaniferous aggregates of potentially commercial deposits must be carefully examined for ulvöspinel by means of polished-section techniques. If this mineral occurs in appreciable amounts and if free ilmenite is lacking, the deposit cannot be benefited by present-day ore-dressing techniques.

PROBLEMS OF MINERAL IDENTIFICATION IN TITANIFEROUS AGGREGATES

Reports describing titaniferous ores frequently use vague or inaccurate mineralogical terms. Much of the confusion in nomenclature arises because the fine-grained intergrowths of ilmenite and iron oxides that are so common cannot be detected unless polished sections of the aggregate are studied under the microscope. Chemical analyses of these aggregates give ratios for titanium and iron that do not correspond to any pure mineral. An investigator confronted with these chemical analyses and unaware that more than one mineral is present may erroneously identify the aggregate as a single mineral, such as "ilmenite," "titaniferous magnetite," "ilmenorutile," or "titanomagnetite." The misidentification greatly complicates the nomenclature of the titaniferous ores by introducing terms that are meaningless in

describing the exact physical and chemical composition of an ore.

The names "arizonite," ilmenite, and leucoxene are often loosely used in describing the mineralogy of sand deposits. Chemical analyses are not enough for determining the mineralogical constituents of titanium-bearing sand, especially where numerous alteration products of titanium are present. Complete chemical, petrographic, and X-ray data are usually essential to determine exact composition. For these reasons, the reader must be careful in accepting data on the amounts and kinds of titanium-bearing minerals in secondary deposits, unless an author gives chemical, petrographic, and preferably also X-ray data to support his identification.

GEOLOGY OF TITANIUM DEPOSITS PRIMARY

DEPOSITS CONTAINING ILMENITE

Most deposits of primary titaniferous minerals contain ilmenite or ilmenite and iron oxides in various physical and chemical combinations. The more important of these deposits are associated with anorthosite complexes, layered norite bodies, other gabbroic rocks, or bodies of nelsonite.

DEPOSITS IN ANORTHOSITIC COMPLEXES

Deposits containing ilmenite are common near the margins of anorthosite massifs and are associated with anorthositic and gabbroic facies of the rock. The anorthosite is generally a coarse-grained, light- to dark-gray rock containing over 90 percent of plagioclase, ranging in composition from andesine to calcic labradorite, accompanied by less than 10 percent ferromagnesian silicates. Less feldspathic gabbroic phases occur as lenses or pods within the anorthosite. The gabbro is a dark, fine-grained rock of plagioclase feldspar and pyroxene, with subordinate hornblende, biotite, and garnet and accessory magnetite, ilmenite, rutile, scapolite, and apatite.

The titanium-bearing bodies are commonly lenses and less often irregular veins, dikes, or large, irregular masses. The size ranges from small lenses that measure about 15 by 80 feet to large, irregular masses, such as the Allard Lake deposit, which is 3,600 feet long, 3,400 feet wide, and at least 300 feet thick.

In composition, the bodies range from masses of pure "ore," without silicate minerals, to grains of titanium minerals irregularly disseminated throughout the gangue of plagioclase and ferromagnesian minerals. Contacts between "ore" and gangue are usually sharp within anorthosite and gradational within gabbro.

Two theories of origin have been presented; one theory postulates emplacement of the ore bodies as magmas, and the other postulates an origin by replacement of the preexisting rock by the titanium minerals. In the magmatic theory it is believed that the bodies of ilmenite-magnetite were injected as a liquid into hot, partly solidified bodies of anorthosite and gabbro that came from the same magmatic reservoir as the ilmenite-magnetite magma. In the replacement theory it is postulated that permeating gases or liquids soaked through the anorthosite and formed the ilmenite-magnetite bodies by molecule-by-molecule replacement of the preexisting host rock.

DEPOSITS IN LAYERED NORITE COMPLEXES

Ilmenite and iron oxides occur in layered, ferromagnesian rock complexes in the Transvaal Province of the Union of South Africa and at Freetown, Sierra Leone.

The Bushveld igneous complex of the Transvaal is a large, saucer-shaped body of banded rocks ranging in composition from bronzitite at the base to granite near the top. The titanium-bearing layers of ilmenite, magnetite, maghemite, and hematite are 1 to 20 feet thick and conformably interlayered with norite and anorthosite only a few thousand feet below the granite that forms the top of the complex. The titaniferous layers dip 5° to 30° toward the center of the complex and occur in 2 distinct horizons that are separated by approximately 1,400 feet of norite. The contact between the titanium-iron bodies and the norite or anorthosite is usually sharp, although in places there is a gradation from norite or anorthosite, through norite, with scattered blebs of ilmenite and magnetite, to labradorite-magnetite-ilmenite rock with equal proportions of opaque and nonopaque minerals, and finally to masses of pure "ore."

The norite complex at Freetown, Sierra Leone, is similar in general features to the Bushveld complex and contains olivine gabbro, gabbro, and norite, with minor amounts of anorthosite, anorthositic gabbro, and peridotite. The titaniferous bodies of ilmenite-magnetite, magnetite-dunite, and magnetite-rich troctolite occur as conformable bands and lenses, generally within the anorthosite.

Various theories have been advanced for the origin of these deposits. Most theories suggest that the ilmenite and magnetite layers crystallized from a liquid fraction of the magma that crystallized to form the silicate layers that are immediately underneath the titaniferous magnetites. It has also been proposed that a magma of ilmenite-magnetite composition was forcefully intruded into an earlier formed norite body.

DEPOSITS IN GABBROIC AND FERROMAGNESIAN COMPLEXES

Many ilmenite-bearing deposits occur in gabbro or other ferromagnesian bodies. The titaniferous portions usually contain gabbro, some with olivine or hornblende, as well as small quantities of anorthosite. In shape and size the bodies range from small dikes 50 to 100 feet wide by 1,500 feet long to saucer-shaped complexes having an outcrop pattern that is 125 miles long by 25 miles wide and covers 2,400 square miles.

The titanium is principally in mixtures of magnetite and ilmenite that have the following occurrences: Mineralized veinlets and stringers; small pockets and lenses within the host rock; dikelike, irregular masses that exhibit a wide range of sizes; and conformable layers within banded gabbro.

Most of the magnetite-ilmenite deposits in these bodies are probably primary and have crystallized from the same magma that formed the enclosing gabbro, dunite, or other ferromagnesian rock.

NELSONITE DEPOSITS

Nelsonite occurs only as irregular masses associated with a small body of anorthosite in Amherst and Nelson Counties, Va. The anorthosite, consisting of approximately 75 percent sodic andesine, 25 percent microcline, and minor quartz and secondary silicates, has light bluish-gray feldspar crystals 10 to 20 cm. in diameter, surrounded by white, granulated feldspar.

Although the nelsonite bodies are irregular, they approximate dikelike or lenticular bodies. They generally have an average maximum dimension of several hundred feet, but a few dikes are as much as 2,000 feet long.

Most of the nelsonite bodies occur near the borders of the anorthosite mass, although ilmenite nelsonite free from rutile occurs in a surrounding body of quartz monzonite; rutile nelsonite is confined solely to the anorthosite and magnetite nelsonite to the quartz monzonite.

The problems concerning the origin of bodies of nelsonite and of bodies of ilmenite in anorthosite are similar. According to one theory, nelsonite bodies crystallized from a magma that either segregated in place from the surrounding anorthosite magma or segregated at depth and was then intruded into partly consolidated anorthosite. The other theory indicates that the nelsonite bodies were formed through replacement of anorthosite by titanium-bearing solutions.

OTHER PRIMARY DEPOSITS CONTAINING ILMENITE

Although the titanium content of some magnetite deposits in New Jersey averages only 3.2

percent TiO_2 , some authors have mentioned the deposits because of their titanium. The field relationships are not clear, yet it appears that the deposits containing small amounts of titanium occur in gneiss, whereas those of higher titanium content occur in metamorphosed gabbro. The latter deposits, which contain as much as 10 percent TiO_2 , therefore are probably similar to other occurrences in gabbroic rocks.

Ilmenite and other titaniferous minerals are common minor constituents of many rocks. For example, analyses of the granite-rhyolite group of rocks indicate an average of 0.4 percent TiO_2 , occurring mostly in ilmenite, titanite-magnetite, rutile, or sphene.

DEPOSITS CONTAINING RUTILE AND BROOKITE**RUTILE IN NELSONITE**

Bodies of rutile in nelsonite, which occur in the anorthosite of Amherst and Nelson Counties, Va., are generally similar to the other nelsonite deposits, except for a higher content of rutile, which in some bodies may compose as much as 60 percent.

DEPOSITS IN ANORTHOSITIC COMPLEXES

In anorthosite rutile occurs either in the anorthosite itself, or in bodies of ilmenite and magnetite or ilmenite and hematite.

Rutile in the nelsonite-bearing anorthosite of Amherst and Nelson Counties, Va., occurs either as irregularly distributed grains or as local segregations. Where disseminated, rutile averages 4 to 5 percent of the rock, but where concentrated into stringers of disconnected rutile grains, it may constitute as much as 30 percent of the rock.

In a few places, such as St. Urbain, Quebec, rutile occurs in irregularly distributed, discontinuous, rutile-rich bands, streaks, or patches in the ilmenite-hematite bodies; however, this type of occurrence does not appear to be common.

DEPOSITS IN ACID DIKES AND VEINS

Rutile, a common minor constituent of quartz veins, pegmatites, and aplite dikes, is concentrated enough in a few places to be mined as ore.

At Kragerø, Norway, rutile has been mined from an aplite dike containing an average of 5 to 10 percent rutile. Schlieren of rutile are irregularly distributed throughout the dike, and grains of rutile are concentrated near the center.

In a few places quartz veins have yielded large rutile crystals for mineralogical collections.

Theories on the origin of the host bodies range from concepts of magmatic emplacement (with the rutile as a minor constituent), to late-stage deposition from circulating gases or liquids.

DEPOSITS OF UNIQUE GEOLOGIC OCCURRENCE IN ARKANSAS

In the Magnet Cove region, Arkansas, deposits of rutile and brookite are associated with novaculite and aegerine phonolite porphyry.

In the Magnet Cove Rutile Co. deposit, rutile occurs in 5 of the 6 differing types of fine-grained feldspar-carbonate veins that cut the aegerine phonolite porphyry. The veins, constituting 50 to 75 percent of the deposit, contain varying amounts of albite, ankerite, apatite, biotite, calcite, dolomite, microcline, perthite, and rutile. One group of these feldspar-carbonate veins was introduced into the aegerine phonolite porphyry and then hydrothermally altered, for the most part, to clay. Afterward, more rutile-bearing feldspar-carbonate veins were emplaced, and finally the deposit was weathered to clay to shallow depths.

An earlier theory, not substantiated by later work, indicated that the rutile occurred in a highly altered volcanic agglomerate between blocks of unaltered igneous material. The volcanic ash and agglomerate were later altered to rutile-bearing clay by titania-rich hydrothermal solutions.

Brookite occurs at the Christy deposit as crystals in porous, light- to dark-gray quartzite masses that are embedded in novaculite and clayey material. The original novaculite and interbedded fine-grained sedimentary rocks were permeated by titanium-bearing solutions that partly recrystallized the novaculite and formed the brookite.

SECONDARY

The secondary deposits are derived from primary bodies by weathering processes that often result in considerable enrichment of titanium-bearing minerals. Many of the deposits are commercially valuable because large-scale mining in the unconsolidated material comprising the ore bodies is relatively inexpensive.

SANDS OF MARINE ORIGIN

Many beaches contain "black," heavy-mineral sands that in places are rich in ilmenite or rutile and their alteration products. Lenses of these heavy sands occur beneath beaches and the adjacent sandy areas. Cross sections normal to the beach front show that the lenses are wedge shaped, with the thickest portion inland. Individual layers range in thickness from a few inches to 5 feet, in width from a few feet to 100, and in length from a few feet to 800. The best deposits extend beneath the beach from the line of approximate mean sea level inland to a point reached by the strongest storm waves. Groups of layers, separated by barren sand, may overlap to form complexes that extend considerable distances along a

coastline. Heavy sands occur also in offshore bars, in lagoons behind barrier beaches, and in sand-dune complexes that extend inland from the present beaches.

Buried, heavy-mineral deposits are common in marine terraces that may be miles inland from the present coast. In Florida sands of marine terraces average 1 to 2 percent heavy minerals to depths of 65 feet. These heavy sands are associated with crossbedded, highly oxidized, clastic sediments, whose pattern of distribution was caused by strong currents.

The heavy-mineral deposits probably form, for the most part, during big storms, when large waves throw sand onto the beach well above the normal high-water mark. The returning water has enough velocity to remove only the lighter mineral grains, leaving a residue of heavy minerals behind.

Although heavy-mineral deposits are common along coasts, commercial titanium-bearing deposits generally form only under the following special conditions: The source material for the sand is generally a tropical or subtropical area of lateritic soil that contains relatively stable minerals, such as ilmenite, rutile, their alteration products, and zircon. These minerals are carried to the ocean and deposited in deltas or along the continental shelf. Finally, these sediments, with their low content of heavy minerals, are reworked on the beaches and concentrated in pockets, layers, and lenses.

STREAM SANDS AND GRAVELS

The sands and gravels in the beds and flood plains of streams contain accumulations of heavy minerals that in places are rich enough in titanium-bearing minerals to be mined. The deposits may be indefinitely bounded zones of sand and gravel in which the heavy minerals are richly disseminated, or may consist of lenses of irregular tabular bodies a few inches thick stratified in the sand and gravel. The heaviest concentrations commonly occur in flats below narrow valleys, gorges, or steep gradients, especially near the bedrock floor of the deposits.

Deltas of some rivers, such as the Nile, contain important heavy-mineral concentrations that are worked for the titanium content.

RESIDUAL DEPOSITS

Surface concentrations of resistant minerals, such as quartz, ilmenite, and rutile, are common in regions where bedrock is chemically weathered. These chemically inert, residual minerals are embedded in unconsolidated sand, silt, and clay that grade downward into bedrock. The concentration of the residual minerals is generally greatest in the upper portion of the deposits and decreases downward to the

normal concentration within bedrock. Because of this upper-zone enrichment, the deposits can be important sources of rutile and ilmenite, even though the bedrock contains only minor amounts of these minerals.

RESIDUAL CLAY DEPOSITS

Deposits of residual clay commonly contain grains of titaniferous minerals derived from the underlying bedrock. For example, in Oregon ferruginous and bauxitic clays that overlie basalt bedrock contain residual grains of ilmenite and magnetite as large as 0.55 mm. in diameter. Some clays have retained the texture of the parent basalt and contain numerous grains of partly altered ilmenite and magnetite in their original spatial arrangement (Libbey, Lowry, and Mason, 64).

Channel and grab samples of ferruginous bauxite deposits in Columbia County, Oreg., contained an average of 5.83 percent TiO_2 and 38.63 percent Al_2O_3 . Clay deposits in Idaho have as much as 8 percent ilmenite and in Washington 7.3 percent TiO_2 .

During chemical weathering the silicates are altered to the clay minerals (hydrated aluminum silicates); but the more resistant minerals, such as quartz, rutile, ilmenite, and zircon, are changed only slightly. The lower part of the section is leached of silica, magnesium, calcium, and sodium, while iron and aluminum are concentrated in the upper part; titanium is relatively little affected and is only slightly concentrated in the upper part. Although very little movement of titanium is shown in the clay deposits in Idaho, Oregon, and Washington, titanium can be mobile in the weathering cycle under special conditions, as shown in the adjacent section that discusses Soils.

BAUXITE

In many places residual grains of ilmenite or leucoxene occur in bauxite, a lateritic material of high alumina content. Large tonnages of this ilmenite are contained in black sands discarded by plants that treat bauxite by the Bayer process. Because at 1 plant this sand averages 5 percent TiO_2 , various methods of recovering the ilmenite have been investigated. In experimental concentration tests (consisting of crushing, screening, tabling, roasting, and magnetic separation) ilmenite concentrates of the following titanium content and recovery were obtained: (1) 17.8 percent TiO_2 , 82.4 percent recovery; (2) 20.7 percent TiO_2 , 51.7 percent recovery; (3) 40.1 percent TiO_2 , 68.3 percent recovery; and (4) 41.2 percent TiO_2 , 35.7 percent recovery (Calhoun, 59, p. 15).

SOILS

Although the average titanium content of soils is only 0.5 to 1.5 percent TiO_2 , some Hawaiian soils average as much as 5 percent TiO_2 , and have local maxima as great as 45.5 percent TiO_2 . These titaniferous soils occur on mountainsides, where alternating dry and wet seasons prevail. The climate farther upslope favors the growth of a tropical-rainfall forest. The titanium-rich, upper part of these soils contains anatase as well as concentrations of iron oxide and averages 15 to 25 percent TiO_2 and 45 to 55 percent Fe_2O_3 . According to Sherman (70), the anatase and iron oxides are deposited in the upper part by solutions that move upward in the soils during the dry season. These solutions are contributed to the soil during the wet season, when titanium-bearing ground water moves downslope from the tropical-rainfall forest above.

CHAPTER 3. RESOURCES ⁵

INTRODUCTION

This chapter summarizes the world resources of titanium and gives, where possible, detailed figures.

All tons used in this chapter are short tons, equal to 2,000 pounds.

In this chapter the word "resources" is employed to designate both titaniferous material minable under present economic conditions and material that cannot be mined economically at present but may have future importance because of technological advances and changes in economic conditions. All of the resource data in this report were gathered from published sources. These publications do not use a universal method of classifying reserves according to grade; many of the authors have their own, individual classification schemes, and some do not even classify the reserves according to grade at all. For this reason, no attempt has been made in this chapter to classify tonnage figures according to grade.

Because the titanium resources are discussed by countries, the tables for each country summarize the resources of all types of titaniferous deposits there. Information as to the kind of titaniferous mineral in a deposit is discussed in the text and in some instances is also given in the resource tables for each country. World-wide resources of rutile, recoverable ilmenite, and nonrecoverable ilmenite are summarized in tables 21 to 25, in order that the reader might know the availability of the various minerals.

The principal commercial deposits that were being mined in early 1955 are as follows: Australia, rutile from coastal beach sands; Canada, primary deposits of ilmenite, magnetite, and hematite in Quebec; Egypt, black sands in the delta of the Nile River; Finland, ilmenite-magnetite deposit at Otanmäki; French Cameroons, placer deposits of rutile; India, beach deposits of ilmenite and rutile along the Travancore coast; Japan, titanium-bearing "iron sands"; Malaya, placer deposits containing ilmenite; Norway, primary bodies of ilmenite and magnetite; Senegal, French West Africa, ilmenite-bearing beach deposits southeast of Dakar; and United States, primary deposits of ilmenite and magnetite and placer deposits of ilmenite and rutile.

¹ By Robert Lawthers, formerly geologist, Federal Geological Survey.

The world production of ilmenite and rutile from 1941 to 1954, as shown in table 19, was 9,953,593 tons of ilmenite concentrate and 420,319 tons of rutile concentrate. These totals do not include the U. S. S. R., as information is lacking, although titanium ores probably were produced.

SUMMARY

The titanium resources of the world, as summarized from the literature and shown in table 20, are 1,937.3 to 2,116.3 million tons of titaniferous material containing 215.7 to 265.3 million tons of TiO_2 . The following must be considered in interpreting these estimates: Many of the resource figures are inferred estimates; resource data are lacking for some of the large, commercially valuable deposits; and not all the contained titanium in a deposit can be recovered.

These summary data have been divided in tables 21 to 25 according to the titanium mineral present. Deposits containing rutile total approximately 265.8 to 276.1 million tons of material having about 10.2 to 10.5 million tons of TiO_2 contained in the rutile (table 21). This figure is not completely accurate, as information is lacking for numerous deposits, such as those in Brazil, French Cameroons, French Equatorial Africa, Norway, and Senegal, as well as domestic deposits in Florida and South Carolina.

TABLE 19.—*Total world production of ilmenite and rutile concentrates, 1941-54, in short tons*

Country	Concentrate, tons	
	Ilmenite	Rutile
Australia	¹ 119, 172	286, 780
Brazil	23, 446	14, 683
Canada	² 419, 401	.....
China	³ 4, 423	.....
Egypt	7, 390	.....
French Cameroons .....	.....	16, 900
French Equatorial Africa .....	.....	⁷
India	2, 817, 770	¹ 10, 779
Japan	⁴ 32, 126	.....
Malaya	231, 104	.....
Norway	1, 320, 203	¹ 823
Portugal	5, 552	.....
Senegal	68, 995	.....
Spain	7, 240	.....
United States	4, 895, 371	90, 354
Total	9, 953, 593	420, 326

¹ 1954 data not available.

² Includes 291,352 tons of titanium slag produced in 1951-54.

³ 1941-44 data only.

⁴ 1925-46 total plus 4,655 tons of titanium slag produced in 1953-54.

TABLE 20.—*Titanium resources of the world, in short tons, as compiled from published information*

Country	Titaniferous material, million tons	Contained TiO ₂ , million tons
Australia.....	14.45	5.20
Canada.....	119.61-207.61	37.55-71.71
Ceylon.....	6.40	2.80
China.....	.24	.03
Egypt.....	15.00	3.86
Finland.....	50.00	6.75
India.....	131.14	38.04
Japan.....	41.63	3.54
Korea.....	2.54	.51
Madagascar.....	3.89	1.04
Mexico.....	27.50	4.81
New Zealand.....	247.44	4.63
Norway.....	166.17	25.70
Sweden.....	243.02	16.70
Union of South Africa.....	25.43	1.27
U. S. S. R.....	145.64	14.49
United States.....	692.19-753.19	49.81-64.21
Total.....	1,937.29-2,116.29	215.73-265.29

Resources of domestic deposits of recoverable ilmenite are summarized in table 22 and total 426.5 to 501.5 million tons of material containing 26.0 to 40.6 million tons of TiO₂ in ilmenite. The ilmenite in these deposits is of sufficient quantity and purity to permit its recovery in ilmenite concentrate containing a minimum of 44 percent TiO₂; however, this ease of recoverability does not imply necessarily that a given deposit is large enough to warrant commercial development. At present some of these de-

posits are being mined to supply ilmenite for use in the pigment industry.

Domestic deposits of titaniferous magnetite and ilmenite that cannot be recovered economically under present technological conditions are shown in table 23. These total 143.6 to 149.3 million tons of material containing 22.0 to 23.0 million tons of TiO₂. The titanium in these deposits occurs either as small amounts in nontitaniferous minerals or in ilmenite that is intimately combined with other minerals, usually magnetite. This occurrence of the titanium makes impossible economic extraction of high-purity titaniferous concentrates by means of present-day ore-dressing techniques. Therefore, utilization of these deposits will require chemical or pyrometallurgical treatment.

Foreign deposits containing recoverable ilmenite are summarized in table 24 and total 477.0 to 565.0 million tons of material containing 108.2 to 142.3 million tons of TiO₂ in ilmenite. Material from Allard Lake, Canada, and from beach deposits in Japan is included in this category, as the titanium is economically extracted in a high-titania slag.

Foreign deposits of titaniferous magnetite and ilmenite that cannot be recovered economically are shown in table 25 and total 541.4 million tons of material containing 49.3 million tons of TiO₂.

TABLE 21.—*World resources of rutile, in short tons*

Country	Titaniferous material	Grade, percent TiO ₂	Rutile	Contained TiO ₂	Remarks
Australia.....	10, 503, 000	-----	2, 689, 000	2, 554, 000	Major source of rutile.
India.....	80, 000, 000	-----	2, 000, 000	1, 900, 000	Deposit in Travancore State. Deposit mined for ilmenite and most of rutile discarded.
Mexico.....	27, 500, 000	17.5	-----	4, 812, 000	Not in production. Reserve estimate from published company figures.
Union of South Africa.....	25, 428, 000	-----	175, 000	167, 000	Not in production. Beach deposits at Umgababa, and lode deposits in South-West Africa.
United States: ¹					
Arkansas.....	2, 250, 000— 12, 500, 000	3.1	-----	70, 000— 388, 000	No production at present. Produced until 1944 but stopped when beneficiation became uneconomical.
Florida.....	² 114, 600, 000	0.5-1.5	-----	545, 000	Important producer of rutile concentrate.
North Carolina.....	³ 229, 000	-----	4, 200	4, 000	3 small, valley placer deposits.
Virginia.....	5, 330, 000	3.0	-----	150, 000	No production at present. Produced at Roseland from 1903 until 1949.
Total.....	265, 840, 000-276, 090, 000 265.8-276.1 million tons			10, 202, 000-10, 520, 000 10.2-10.5 million tons	

NOTE: Resource figures not available for rutile deposits in Brazil, French Cameroons, French Equatorial Africa, Norway, and Senegal.

¹ No resource figures for deposit being mined in South Carolina.

² Large, active deposit contains rutile, but no reserve figures are available.

³ Total weight of heavy minerals.

TABLE 22.—United States resources of ilmenite recoverable under present technological conditions, in short tons

State	Deposit	Titaniferous material	Grade, percent TiO ₂	Contained TiO ₂	Remarks
Florida-----	Numerous buried beach placers.	66, 700, 000	0. 8	560, 000–15, 000, 000	Producer.
Idaho-----	Valley County placers.	225, 000, 000–300, 000, 000	. 14	270, 000–450, 000	Ilmenite recovered as a by-product of monazite mining.
New York-----	MacIntyre operation.	100, 000, 000	20. 0	20, 000, 000	Most important producer of ilmenite for pigments. Reserves of 1 operator.
North Carolina---	Three valley placers.	¹ 229, 000	14. 8	34, 000	No production. Probably not large enough to be mined economically.
Oklahoma-----	Lake Lawtonka---	8, 530, 000	1. 9	163, 000	No production. Preliminary tests indicate that concentrates contain 44.1 percent TiO ₂ .
Virginia-----	Amherst-Nelson County area.	26, 000, 000	19. 2	5, 000, 000	Producer of ilmenite.
Total-----		426, 459, 000–501, 459, 000 426. 5–501. 5 million tons		26, 027, 000–40, 647, 000 26. 0–40. 6 million tons	

¹ Total weight of heavy minerals, of which 65,700 tons is ilmenite.

TABLE 23.—United States resources of titaniferous magnetite and ilmenite not recoverable under present technological conditions, in short tons

State	Deposit	Titaniferous material	Grade, percent TiO ₂	Contained TiO ₂	Remarks
California-----	San Gabriel Mountains.	250, 000–6, 000, 000	18. 0	45, 000–1, 050, 000	Area was investigated by a large company, but no development work was undertaken.
Idaho and Washington.	High-alumina clay deposits.	(Not given)	7. 3–8. 0	1, 040, 000	Ilmenite available only as a byproduct if clay is mined for its aluminum.
Minnesota-----	Duluth gabbro-----	94, 600, 000	14. 0–23. 0	14, 414, 000	
Montana-----	Titaniferous sandstone.	4, 500, 000	6. 0	270, 000	
New York-----	Calamity Mill Pond and Iron Mountain.	21, 500, 000	17. 2–24. 0	3, 960, 000	
Oregon-----	Ferruginous bauxite.	6, 552, 000	4. 9	319, 000	Ilmenite available as a by-product only if bauxite is mined for its aluminum.
Rhode Island---	Iron Mine Hill-----	7, 000, 000	9. 8	686, 000	
Wyoming-----	Iron Mountain-----	9, 150, 000	14. 0	1, 278, 000	
Total-----		143,552,000–149,302,000 143.6–149.3 million tons		22,012,000–23,017,000 22.0–23.0 million tons	

NORTH AMERICA

UNITED STATES

Production of titanium ores in the United States between 1941 and 1954 has totaled 4,895,371 tons of ilmenite concentrate and 90,354 tons of rutile concentrate. As shown in

table 26, the titanium resources of this country are 692.2 to 783.2 million tons of titaniferous material containing 48.8 to 64.2 million tons of TiO₂.

Principal production of titanium concentrate has been from deposits in Arkansas, California, Florida, Idaho, New York, North Carolina, South Carolina, and Virginia. Small produc-

TABLE 24.—*Foreign resources of ilmenite recoverable under present technological conditions, in short tons*

Country	Titaniferous material	Grade, percent TiO ₂	Contained TiO ₂	Remarks
Australia.....	10, 503, 000		2, 230, 000	Ilmenite is a byproduct of rutile industry but cannot be used for pigment because of high chromium content.
Canada.....	113, 300, 000–201, 300, 000	35. 0	36, 321, 000–70, 481, 000	Deposit at St. Urbain yields ilmenite concentrate. Ore from deposit at Allard Lake is smelted to yield a slag containing 70 percent TiO ₂ .
Egypt.....	15, 000, 000	25. 7	3, 855, 000	In production.
Finland.....	50, 000, 000	13. 5	6, 750, 000	Deposit at Otanmäki; in production.
India.....	80, 000, 000	37. 5	30, 000, 000	Deposits in Travancore State. Important producer of ilmenite.
Japan.....	41, 632, 000	8. 5	3, 539, 000	Ore is smelted to yield a titaniferous slag.
Norway.....	143, 299, 000	17. 0	24, 361, 000	Storgangen and Tellnes deposits in Eker-sund-Soggendal area. Important producer.
Union of South Africa...	23, 300, 000	4. 7	1, 100, 000	No production. Beach deposits at Umga-baba.
Total.....	477, 034, 000–565, 034, 000 477.0–565.0 million tons			108, 156, 000–142, 316, 000 108.2–142.3 million tons

TABLE 25.—*Foreign resources of titaniferous magnetite and ilmenite not recoverable under present technological conditions, in short tons*

Country	Titaniferous material	Grade, percent TiO ₂	Contained TiO ₂	Remarks
Australia.....	3, 944, 000	12. 7	420, 000	Titaniferous magnetite deposits in New South Wales and Western Australia.
Canada.....	6, 310, 000	19. 5	1, 227, 000	Some of this material may be recoverable.
Ceylon.....	6, 400, 000	43. 7	2, 800, 000	
China (Formosa).....	243, 000	11. 0	27, 000	Numerous small deposits.
India.....	51, 143, 000	12. 0	6, 136, 000	
Korea.....	2, 535, 000	20. 0	507, 000	Will not economically yield ilmenite concentrates.
Madagascar.....	3, 887, 000	26. 9	1, 045, 000	
New Zealand.....	50, 393, 000	9. 2	4, 627, 000	May be exploited, but no information available.
Norway.....	22, 873, 000	5. 9	1, 342, 000	
Sweden.....	248, 017, 000	6. 7	16, 701, 000	
U S. S. R.....	145, 638, 000	9. 9	14, 490, 000	
Total.....	541, 383, 000 541.4 million tons			49, 322, 000 49.3 million tons

tion, some of it for gems and experimental purposes, has been reported from additional deposits in Connecticut, Georgia, Pennsylvania, Rhode Island, South Carolina, and Wyoming. Although deposits of titanium minerals have been reported from almost every State in the country, many occurrences have only mineralogical interest or negligible commercial importance. In this chapter deposits in the following States are discussed: Arkansas, California, Colorado, Florida, Georgia, Idaho, Maryland, Minnesota, Montana, Nevada, New York, North Carolina, Oklahoma, Oregon, Pennsylvania, Rhode Island,

South Carolina, Texas, Virginia, Washington, and Wyoming. Deposits in Hawaii are discussed at the end of the section on the United States.

ARKANSAS

Production of titanium concentrate from Arkansas has never been large and has totaled only 5,188 tons of rutile concentrate produced from 1932 to 1944. Estimates of resources, mostly from the Magnet Cove area, range from 2,250,000 tons of rutile "ore" containing 70,000 tons of TiO₂ (Matthews, Ralston, and Ross (87,

TABLE 26.—*Titanium resources of the United States, in short tons*

State	Titaniferous material	TiO ₂
Arkansas.....	2, 250, 000–12, 500, 000	70, 000–388, 000
California.....	250, 000–6, 000, 000	45, 000–1, 050, 000
Florida.....	181, 300, 000	1, 105, 000–15, 000, 000
Idaho (placer deposits).....	225, 000, 000–300, 000, 000	270, 000–450, 000
Minnesota.....	94, 600, 000	14, 414, 000
Montana.....	4, 500, 000	270, 000
New York.....	121, 500, 000	23, 960, 000
North Carolina.....	229, 000	38, 000
Oklahoma.....	8, 530, 000	163, 000
Oregon.....	6, 552, 000	319, 000
Rhode Island.....	7, 000, 000	686, 000
Virginia.....	31, 330, 000	5, 150, 000
Washington and Idaho (clay deposits).....	Not given	1, 040, 000
Wyoming.....	9, 150, 000	1, 278, 000
Total.....	{ 692, 191, 000–783, 191, 000 692.2–783.2 million tons	48, 808, 000–64, 206, 000 48.8–64.2 million tons

table 38)) to 12,500,000 tons of "ore" (U. S. Senate Committee on Interior and Insular Affairs (96, p. 257)) containing an estimated 388,000 tons of TiO₂.

The principal deposits occur in the Magnet Cove region, approximately 8 miles northwest of Malvern, Hot Spring County, and have been discussed by Fryklund, Harner, and Kaiser (80). At the Magnet Cove Rutile Co. deposit, where rutile was mined between 1932 and 1944, rutile-bearing feldspar-carbonate veins in an aegirine porphyry average 3 to 4 percent TiO₂. Preliminary beneficiation tests made in 1949 indicated that a rutile concentrate of 92.2 percent TiO₂ could be obtained, with a recovery of 46.4 percent. Recent work indicates that rutile from this deposit averages about 1.2 percent columbium (niobium).

The Christy deposit is small and averages about 5.8 percent TiO₂, mostly in brookite; it has not been mined. Tests have shown that the brookite can be concentrated to a product of 92.8 percent TiO₂ with a recovery of 60.6 percent.

Other deposits in the Magnet Cove region include the Hardy-Walsh brookite deposit (Kilpatrick brookite deposit) containing 5.0 to 8.4 percent TiO₂, the Mo-Ti Corp. deposit containing 1.2 percent TiO₂, and the Kimsey Calcite quarry containing approximately 1 percent TiO₂. Perovskite, the principal titanium mineral in the Kimsey deposit, contains 5.1 to 8.8 percent columbium (niobium).

Two small deposits of ilmenite-bearing sand in the Tokio formation of late Cretaceous age northwest of Mineral Springs, Howard County, contain approximately 4 percent TiO₂.

CALIFORNIA

Resource estimates for California deposits vary. According to Matthews, Ralston, and

Ross (87, table 38), the State contains 250,000 tons of "ore" having an average grade of 18 percent TiO₂; this is equivalent to 100,000 tons of ilmenite or 45,000 tons of TiO₂. On the other hand, Oakeshott (89, p. 353) has estimated that deposits in the San Gabriel Range alone total 300,000 to 6,000,000 tons of titaniferous material containing 52,500 to 1,050,000 tons of TiO₂.

Production from the San Gabriel deposits and beach deposits in Los Angeles County totaled 10,013 tons of concentrates during 1927 and 1928, 705 tons from 1939 to 1944, and an unknown but presumably small amount from 1946 to 1950.

In Los Angeles County beach sands averaging 7 percent ilmenite were mined between Hermosa and Palos Verdes during 1927 and 1928 and from 1939 to 1944.

In Sand Canyon and Pacoima Canyon of the San Gabriel Mountains placer deposits contain 2 to 30 percent TiO₂ to depths of 30 to 50 feet. One deposit in Sand Canyon was mined during 1946–50 and the concentrate used in roofing granules and welding-rod coatings. Because of small intergrowths between ilmenite and magnetite, the highest grade titanium concentrate contained 32.6 percent TiO₂ and was obtained with a recovery of only 18 percent.

Numerous bodies of ilmenite and magnetite occur in anorthosite and gabbro of the San Gabriel Mountains. Although some of the bodies are large, they have not been exploited because the small intergrowths of ilmenite and magnetite make it impossible to obtain high-purity ilmenite concentrate. Ilmenite-magnetite "ore" mined near Lang in 1927 and 1928 contained 19.6 percent TiO₂, 46.1 percent Fe, and 0.53 percent V₂O₅. The San Gabriel area was explored extensively from 1927 to 1938 but never developed.

COLORADO

The Cebolla Creek perovskite deposit, 1 of the 3 titaniferous deposits in Colorado, was reportedly being explored and tested in early 1955. This deposit, south of Powderhorn in the southern part of Gunnison County, consists of dikes and lenses of coarse-grained magnetite and perovskite in gabbro and contact-metamorphosed limestone. The mineralized parts contain 9 to 36 percent TiO_2 .

At Caribou Hill, Boulder County, ferromagnesian dikes within Precambrian granite and gneiss contain 8.5 percent ilmenite and 67 percent magnetite in small pockets and lenses. At Iron Mountain, Fremont County, magnetite-ilmenite lenses in anorthosite and gabbro contain 13 percent TiO_2 and 48 percent iron.

FLORIDA

In Florida titanium-bearing sands were first mined in 1916 and during early 1955 formed a large part of this country's production of titanium ores. Estimates of resources range from approximately 181 million tons of rutile and ilmenite-bearing sand containing about 1 million tons of TiO_2 to 25 to 30 million tons of ilmenite, equivalent to 13 to 15 million tons of TiO_2 (table 27).

Although buried titaniferous sands in Florida usually average less than 5 percent heavy minerals, they can be mined economically by dredging. Mining of such deposits by dredges became feasible only during World War II, when development of specific mining and concentrating equipment made treatment of low-grade sands possible.

Eight to ten miles east of Jacksonville the Humphreys Gold Corp. is mining buried sands for the Rutile Mining Co. of Florida and the National Lead Co. The sand contains 3 to 4 percent heavy minerals. The following concentrates are produced by treating the ores in Humphrey spirals, electromagnetic separators, and electrostatic separators: An ilmenite concentrate containing 60 percent TiO_2 ; a rutile concentrate containing 92 percent TiO_2 ; a zircon concentrate of 98 percent zircon; and a monazite concentrate of 95 percent monazite.

East of Starke in the State-owned land of Camp Blanding, Humphreys Gold Corp. is operating the Trail Ridge mine and concentration plant for E. I. du Pont de Nemours & Co., Inc. Buried sands averaging 2 to 4 percent heavy minerals are mined by a floating dredge and upgraded in Humphreys spirals to yield a concentrate of 85 percent heavy minerals. This concentrate is treated by electromagnetic and electrostatic separators to yield an ilmenite concentrate of 63 percent TiO_2 , a mixed ilmenite-leucoxene-rutile product of 80 percent TiO_2 , and concentrates of staurolite and zircon. Annual production is estimated to be 100,000 tons of titanium minerals. The same companies began operations in early 1955 at their Highland plant near Lawtey, Bradford County, about 17 miles north of the Trail Ridge plant. This operation is similar in mining and beneficiation methods to the Trail Ridge plant and is expected to have an annual output of about 100,000 tons of titaniferous concentrates.

Near Vero Beach and Wabasso, the Florida Ore Processing Co. is mining beach and dune sands for ilmenite, rutile, zircon, and garnet.

TABLE 27.—Titanium resources of Florida, in short tons

Deposit	Kind of deposit	Titaniferous material	Grade, percent TiO_2	TiO_2	Remarks
Near Jacksonville; operated for National Lead Co. and Rutile Mining Co. of Florida.	Buried beach sands.	¹ 114, 600, 000	0. 5-1. 5	545, 000	Produces ilmenite and rutile. Listed in reference as rutile deposit only.
Trail Ridge deposit, Starke, operated for Du Pont.	do		1. 3-1. 8		Reserve figures not available for this important producer.
Highland deposit, Lawtey, operated for Du Pont.	do				Important producer.
Florida Ore Processing Co., Vero Beach.	Buried and modern beach sands.	¹ 66, 700, 000	8	560, 000	Listed in reference as ilmenite producer only.
Total of all buried beach deposits.				³ 13, 000, 000-15, 000, 000	Estimated order of magnitude only.
Total		181, 300, 000		14, 105, 000-16, 105, 000	

¹ Matthews, A. F., Ralston, O. C., and Ross, C. S. (88).

² Although new reserves have been discovered since these estimates were made available in 1947, no published data on tonnage are available.

³ Cannon, H. B. (76).

Other deposits of heavy minerals occur throughout the State. Extensive test drilling in 1947 and 1948 showed that the buried sands of central Florida average 1 to 2 percent heavy minerals and in a few places exceed 3 percent (Thoenen and Warne (94)). The heavy-mineral fraction of these sands contains 45 percent ilmenite and leucosene, 4.6 percent rutile, and staurolite, zircon, and ferromagnesian minerals. Beach sands in the Pensacola Bay area contain 1 percent ilmenite and 0.1 percent rutile.

Active exploration for titaniferous sands was being carried out by various companies during early 1955. The Crane Co. reportedly found potentially commercial deposits on Gulf coast beaches near Panama City in 1954. The National Lead Co. in early 1955 acquired a large tract of land in Baker, Bradford, Clay, and Duval Counties. Extensive exploratory work is also reported from the northeast corner of the State.

GEORGIA

During the late 19th century, quartzite and quartz veins at Graves Mountain, Lincoln County, Ga., were mined for rutile to be used as mineralogical specimens and gems.

Deposits of titaniferous heavy sands have been observed near the southern end of St. Simons Island, at the northern end of Long Island, and near the southern end of Sapelo Island. Because the beaches and coastal plain terraces are favorable sites for accumulations of heavy minerals, exploration for economic deposits was undertaken during early 1955 by several companies.

IDAHO

Placer deposits in streams draining the west and southwest flanks of the Idaho batholith contain appreciable amounts of ilmenite and monazite. Estimates are that Long Valley alone contains 600,000 to 1,000,000 tons of ilmenite in deposits totaling 150 to 200 million cubic yards of gravel (Hubbard (85, p. 68)). Assuming that the ilmenite contains about 45 percent TiO_2 , this tonnage represents 270,000 to 450,000 tons of TiO_2 . During early 1955 three companies were dredging the valley south of Cascade primarily for monazite and stockpiling the ilmenite as a byproduct at their Boise processing plant.

In Bear Valley, Valley County, one company that is mining euxenite and monazite is reportedly stockpiling the ilmenite at its processing plant at Lowman. Reserves of this deposit are supposedly large enough for 20 to 25 years of mining.

High-alumina clay deposits in Latah County contain moderate amounts of ilmenite and in

places as much as 8 percent TiO_2 . Estimates of some of the deposits in Idaho and Washington indicate a titanium content of 1,040,000 tons of TiO_2 (Scheid (91); Scheid and Sohn (92)).

MARYLAND

Rutile-bearing deposits occur in a belt of serpentine rocks that extends northward 5 miles from a point 1 mile northwest of Pylesville, Harford County. One abandoned mine in this belt contains pockets of rutile that average 8 percent TiO_2 .

Beach sands along Chesapeake Bay contain heavy minerals at many places. During early 1955 a deposit at Cove Point was being developed for titaniferous and other heavy minerals, but by early 1956 no production had been reported.

MINNESOTA

Low-grade deposits of ilmenite and magnetite are associated with the Duluth gabbro along the north shore of Lake Superior. Resources are estimated to be 94.6 million tons of "ore" in bodies of more than 100,000 tons each and 81.6 million tons of "ore" in bodies of more than 1 million tons each (Grout (83, pp. 85-86)). Calculations based on an average grade of 14 percent TiO_2 in the larger deposits and 23 percent TiO_2 in the smaller deposits (Grout (83, p. 93)) indicate a titanium content of about 14,414,000 tons of TiO_2 .

The Duluth gabbro, a complex consisting mostly of gabbro and anorthosite with minor pyroxenite and peridotite, contains ilmenite and magnetite in bands, dikes, and irregular bodies. The largest deposits occur in the North and South Ranges of Cook County; smaller deposits occur in Lake County. Analyses of cores obtained from a drilling program in 1947 show 3.4 to 25.0 percent TiO_2 and 10.8 to 37.4 percent iron.

The deposits are not commercially economic at present, because the large bodies are of low grade and the rich bodies too small. Beneficiation tests indicate that the small intergrowths between ilmenite and magnetite make it impossible to obtain large amounts of high-grade ilmenite concentrates.

MONTANA

In Glacier, Pondera, and Teton Counties, Mont., the Horseshoe sandstone of Late Cretaceous age contains irregularly distributed heavy mineral lenses rich in ilmenite and magnetite. Drilling of the deposits northwest of Choteau, Teton County, contracted by the Federal Bureau of Mines in 1945, showed that the richer beds averaged 5.9 percent TiO_2 and 38.8 percent iron. Beneficiation tests indicated

that it was impossible to obtain good concentrates of magnetite or ilmenite by grinding, screening, sink-float, or magnetic separation. The only resource estimate claims that the deposits in Teton County contain 4,500,000 tons of titaniferous magnetite having an average grade of 6.0 percent TiO_2 (Mining World (88)).

NEVADA

Anatase occurs in the Corral Canyon mine on the eastern flank of the Stillwater Range, northern Churchill County, approximately 70 miles south of Winnemucca. Altered feldspathic dikes in diorite contain as much as 5 percent anatase and average about 2 percent TiO_2 . Preliminary tests showed that it was possible to produce a concentrate of 63 percent TiO_2 with a recovery of 11 percent and a concentrate of 52 percent TiO_2 with a recovery of 36.5 percent.

The Blue Metal corundum property in Douglas County, approximately 20 miles west of Yerington, contains small amounts of rutile that can be concentrated to a product of 16 percent TiO_2 , with a recovery of 14.8 percent.

NEW YORK

A large part of this country's production of titanium ores comes from the area around Lake Sanford, Essex County, N. Y. The announcement by the National Lead Co. in October 1955 of the discovery of a new deposit near Lake Sanford has raised the total resources of the area to about 121,500,000 tons of material, containing an estimated 23,960,000 tons of TiO_2 . Probably about 100 million tons of these resources can be exploited by present-day ore-dressing techniques.

The only producer in the area, the National Lead Co., mines ore containing 18 to 20 percent TiO_2 and 34 percent iron at its MacIntyre operation at Tahawus. The deposit is variously referred to as the Lake Sanford, Sanford Lake, Tahawus, MacIntyre, Iron Hill, or Sanford Hill deposit and consists of coarse-grained ilmenite and magnetite and associated silicate minerals in anorthosite and gabbro. Ilmenite concentrate averages 44 to 48 percent TiO_2 ; magnetite concentrate contains 9 to 10 percent TiO_2 and 56 percent iron. The new find, announced in October 1955, is assumed to be within the area of the Cheney Pond deposit, formerly considered in the literature as a small body of no commercial importance. Other deposits in this area, all within 2 miles of the present mine, are the Iron Mountain deposit containing 19.4 percent TiO_2 and the Calamity Mill Pond deposit containing 17.2 percent TiO_2 . Resources of the individual deposits are shown in table 28.

TABLE 28.—*Titanium resources of New York, in short tons*

Deposit	Titaniferous material	Grade, percent TiO_2	TiO_2
MacIntyre operation and new deposit.....	¹ 100, 000, 000	20. 0	20, 000, 000
Calamity Mill Pond.....	² 9, 500, 000	17. 2	1, 630, 000
Iron Mountain.....	² 12, 000, 000	19. 4	2, 330, 000
Total.....	121, 500, 000	-----	23, 960, 000

¹ Engineering and Mining Journal (78, p. 73).

² Balsley, J. R. (74, pp. 99-123).

Small deposits of magnetite and ilmenite in the area around Elizabethtown, Mineville, and Westport, Essex County, were not minable under economic and technological conditions of 1955 because they are lean and contain numerous small intergrowths of ilmenite and magnetite.

NORTH CAROLINA

In North Carolina ilmenite occurs in primary deposits, and ilmenite and rutile occur in stream placer deposits. Estimates of material in 3 placer deposits are 229,000 tons of heavy minerals containing 65,700 tons of ilmenite and 4,700 tons of rutile, equivalent to 38,400 tons of TiO_2 (table 29).

Ilmenite and magnetite bodies containing 4.5 to 39 percent TiO_2 occur as veins and dikes in gneiss, schist, and serpentine in the mountains and foothills. The best deposits are in a 30-mile-long belt that trends northeast across northwestern Guilford County and extends into adjacent Davidson and Rockingham Counties. Similar deposits occur in Alleghany, Ashe, Avery, Caldwell, Catawba, Davie, Lincoln, Macon, Madison, Mitchell, and Yancey Counties.

Various placer deposits were investigated during 1952 and 1953 by the Federal Geological Survey and the Federal Bureau of Mines. These stream-placer deposits in the Piedmont contain ilmenite and rutile as well as monazite and other heavy minerals. Although the percentage of titanium minerals is low, they might be recovered if some of the other heavy minerals, especially the monazite, were recovered and marketed. Results of the investigations have been made available for the deposits listed below and are summarized in table 29. The Buffalo Creek deposit occurs in northeastern Cleveland County and northwestern Lincoln County, where Buffalo Creek is joined by its tributary, Glen Creek. The First Broad River placer deposit, in Cleveland

TABLE 29.—*Titanium resources of North Carolina, in short tons*

Deposit	Heavy minerals	Ilmenite	Rutile	TiO ₂
Buffalo Creek ¹	42,000	8,000	1,000	5,200
First Broad River ²	156,000	50,000	3,200	29,200
Knob Creek ³	31,000	7,700	—	4,000
Total	229,000	65,700	4,200	38,400

¹ Griffith, R. F., and Overstreet, W. C. (81).² Hansen, L. A., and Cuppels, N. P. (84).³ Griffith, R. F., and Overstreet, W. C. (82).

County, extends 5.7 miles along the river near Polkville and is 15.6 miles northwest of Shelby. The Knob Creek placer deposit in northeastern Cleveland County is near the confluence of Knob Creek and Little Knob Creek, about 10 miles upstream from the junction with the First Broad River.

The only titanium-mining operation in the State was on the Yadkin River, approximately 14 miles north of Lenoir, Caldwell County, where the Yadkin Mica & Ilmenite Co., a subsidiary of the Glidden Co., mined ilmenite from talcose and chloritic schist. The ore contained 50 to 70 percent ilmenite and 30 to 49 percent TiO₂; concentrate contained 51 to 52 percent TiO₂. Mining was begun in January 1942 and ceased in the fall of 1952.

The Coastal Plain sands and gravels, beaches along the coast, and the beach and underwater deposits of Albemarle Sound have been extensively prospected by various companies, but to date no commercial concentrations have been reported.

An undeveloped residual deposit of rutile near Shooting Creek, 3½ miles east of Hayesville, Clay County, reportedly contains 50 pounds of rutile per cubic yard of material.

OKLAHOMA

In Comanche and Kiowa Counties small bodies of ilmenite and magnetite occur as pods and irregularly shaped dikes in anorthosite and gabbro of the Wichita Mountains. Most of the bodies are small and discontinuous and contain only small amounts of titanium minerals. Two samples of typical titanium-bearing aggregates contained 4.4 and 5.2 percent TiO₂. Estimates of resources of these deposits are not available.

An investigation of the alluvial deposits in the Wichita Mountains showed that the only potentially economic deposit of ilmenite-bearing sand occurs on the north shore of Lake Lawtonka, Comanche County. Ilmenite averages about 4.3 percent by weight of the deposits and in preliminary tests was obtained in a concentrate of 44.1 percent TiO₂. Estimates of material in this deposit indicate 8,530,000 tons

of sand containing 370,000 tons of ilmenite or 163,000 tons of contained TiO₂ (Chase (76)).

OREGON

Concentrations of titaniferous minerals occur in sand along the coast and in ferruginous bauxite of northwestern Oregon. A reconnaissance survey of the coastal beach sands indicated that they contain 25,000 tons of ilmenite and chromite (Twenhofel (95)). Ferruginous bauxite deposits in Columbia and Washington Counties total 6.6 million tons and contain 319,000 tons of TiO₂ (Libbey, Lowry, and Mason (86)).

Black sands containing ilmenite are abundant on the beaches and in the terraces along the Oregon coast. Chromite is intergrown with the ilmenite in the sands along the southern part of the coast, especially south of Coos Bay, where the chromite is more abundant than ilmenite. The content of chromite decreases northward, and north of Tillamook Head chromite is essentially absent. The intergrown nature of the chromite and ilmenite makes it impossible to concentrate the ilmenite.

The ferruginous bauxite deposits of northwestern Oregon contain ilmenite that represents a potential source of titanium if the deposits are ever mined for their aluminum. The bauxite in Columbia, Multnomah, and Washington Counties contains 1.5 to 6.1 percent TiO₂ and that in Marion and Polk Counties 1.0 to 5.2 percent TiO₂. According to Libbey, Lowry, and Mason (86), deposits in Columbia County contain 952,000 tons of material having 47,600 tons of TiO₂ and those in Washington County 5,600,000 tons of material containing 27,600 tons of TiO₂.

PENNSYLVANIA

Pennsylvania was the principal domestic source of rutile before the rutile deposits in Virginia were opened in 1901. The annual production of a few hundred pounds of rutile came mostly from Chester County.

In Bucks County, near Durham, small deposits of titaniferous magnetite contain 3 to 6 percent TiO₂.

RHODE ISLAND

In northeastern Rhode Island about 3 miles east of Woonsocket, near the town of Cumberland, a large titaniferous deposit occurs at Iron Mine Hill. Cumberlandite, the principal rock in the deposit, consists of olivine, labradorite, and a fine-grained mixture of intergrown ilmenite and magnetite. Preliminary beneficiation tests indicate that the fine-grained nature of the ilmenite and magnetite makes it impossible to

obtain concentrates of either magnetite or ilmenite. The deposit averages about 9.8 percent TiO_2 and 33.4 percent iron and contains an estimated 7 million tons of material (Driver (77)).

SOUTH CAROLINA

South Carolina, like Georgia and North Carolina, has deposits of ilmenite and rutile in stream placers of the Piedmont, in buried beach placers of the Coastal Plain terraces, and in modern beach placers along the present shore. Estimates of resources in these deposits are not available.

At present Marine Minerals, Inc., a subsidiary of the Crane Co., is mining a stream-placer deposit along Horse Creek near Aiken. The sands are mined by bucketline dredge and concentrated in a nearby plant. Although reportedly the operation is intended to supply rutile to the Crane plant at Chattanooga, other minerals, such as ilmenite, monazite, and zircon, will be recovered.

TEXAS

The only titaniferous deposit of possible economic significance in Texas is the Mueller prospect in south central Jeff Davis County about 15 miles southwest of Fort Davis. Small crystals and aggregates of rutile are disseminated through hard, silicified volcanic tuff and ash. Preliminary beneficiation tests of samples containing 11 to 34 percent TiO_2 showed that the best concentrate contained 87 percent TiO_2 and was obtained with a recovery of 67 percent. Resources are probably too small to warrant commercial development.

VIRGINIA

Titanium ore has been mined in Virginia since 1901, and before 1942 Virginia was the principal domestic producer of titanium ore. In 1947 reserves were estimated at 26,000,000 tons of ilmenite "ore" and 5,330,000 tons of rutile "ore," both containing a total of 5,150,000 tons of TiO_2 (Matthews, Ralston, and Ross (87, table 38)).

At present, the only titanium-mining operation in the State is at Piney River, where the Calco Chemical Division of the American Cyanamid Co. is mining ilmenite as feed for its nearby pigment plant. The ore occurs in a dike-like body of nelsonite, one of many such similar bodies in the anorthosite mass of Amherst and Nelson Counties. The ore averages about 17 percent TiO_2 in the weathered portions and about 14 percent TiO_2 in unweathered parts.

Before 1949 rutile was mined by the American Rutile Co. at its mine near Roseland. The deposit of disseminated rutile and ilmenite in anorthosite averaged about 5 percent TiO_2 .

Rutile concentrate from this operation contained 86 to 99 percent TiO_2 .

The numerous dikes of nelsonite and bodies of disseminated rutile in Amherst and Nelson Counties represent potential sources of titanium ore. Some of these titaniferous bodies have been mined in the past, some have been prospected extensively, and others are virtually untouched.

Bodies of nelsonite on the Bush and Hutchins farms, Roanoke County, approximately 4 miles east of Roanoke, contain 9 to 16 percent TiO_2 and were mined briefly during 1943.

Small, commercially unimportant deposits of titanium have been reported from Buckingham, Campbell, Carroll, Charlotte, Franklin, Grayson, Goochland, Hanover, Prince Edward, and Rockbridge Counties.

WASHINGTON

Deposits of titanium-bearing minerals in Washington are mostly small, and by 1955 no production has been reported. Near Elma, Grays Harbor County, beds of black sand over an area of 2 to 3 acres are 1 to 4 feet thick and reportedly contain 22 percent TiO_2 and 50 percent iron. The Excelsior clay deposit, 11 miles southeast of Spokane, Spokane County, contains 7.3 percent TiO_2 , 8.2 percent Fe_2O_3 , and 31.1 percent Al_2O_3 . Resource estimates of some of the high-alumina clays in Idaho and Washington indicate a titanium content of 1,040,000 tons of TiO_2 (Scheid (91); Scheid and Sohn (92)).

WYOMING

Deposits of ilmenite and magnetite were discovered in the Laramie Range, Albany County, in 1853 but have not been extensively worked. Recent estimates show that the largest deposit in the State, at Iron Mountain, contains 9,150,000 tons of "ore" (Osterwald and Osterwald (90, p. 87)) equivalent to 1,278,000 tons of TiO_2 . Resource estimates released by the Union Pacific Railroad in early 1954 indicated 178 million tons of "ore" containing 10 percent TiO_2 in the Iron Mountain area (Engineering and Mining Journal (79)). Because further details are lacking, these figures are not included in the resource information of table 26.

The Iron Mountain deposit is in secs. 22, 26, and 27, T. 19 N., R. 71 W., Albany County, about 47 miles by road northeast of Laramie. The dike-like body consists of overlapping lenses and tabular bodies of magnetite and ilmenite in anorthosite. The highest grade material contains large, individual grains of ilmenite and magnetite and ranges in grade from 16 to 23 percent TiO_2 . Leaner grades contain numerous inclusions of ilmenite in magnetite and cannot be beneficiated to marketable concentrates of

ilmenite or magnetite. Recently the Union Pacific Railroad has undertaken a large program of exploration and testing to determine if the deposit can be utilized under present economic conditions.

Other smaller deposits near Iron Mountain include the Shanton deposit, containing approximately 20 percent TiO_2 , and the Taylor deposit, containing 5 to 31 percent TiO_2 .

HAWAII

Titanium occurs in some of the older Hawaiian soils in amounts ranging from 6 to 35 percent TiO_2 , usually in fine-grained mixtures of anatase and iron oxides. The average thickness of these titaniferous soils is about 3 to 4 feet, and the maximum thickness apparently seldom exceeds 10 feet. The deposits occur on the principal islands and are largest on Kauai.

According to Sherman (93), utilization of the deposits appears unlikely at present for the following reasons: (1) The fine-grained nature of the titanium-bearing minerals and their intimate association with iron oxides make them unsuitable for beneficiation by present-day ore-dressing techniques; (2) the size and scattered locations of the deposits would not justify the installation of expensive equipment for mining and beneficiation; and (3) the steepness of the slopes on which the deposits occur would necessitate the use of special, mobile equipment for development.

CANADA

Titaniferous deposits are abundant in Canada, particularly in the Province of Quebec, and total 119.6 to 207.6 million tons of material containing 37.5 to 71.7 million tons of TiO_2 (table 30). A comprehensive summary on Canadian deposits is given by Robinson (105). Production between 1941 and 1954 has been

419,401 tons of titanium concentrate, including titanium-bearing slag.

In Canada the largest known titaniferous deposit occurs at Allard Lake, where the Quebec Iron & Titanium Corp. is mining ore containing 35 percent TiO_2 and 36 to 40 percent iron. The ore consists predominantly of ilmenite but includes also about 15 percent hematite as sub-microscopic lamellae within the ilmenite. Development of the deposit was begun in 1948, and by July 1950 the first shipment of ore was made from the docks at Havre St. Pierre, 28 miles south of the deposit. From Havre St. Pierre the ore is shipped via boat to the smelter at Sorel, 50 miles downstream from Montreal. Smelting of the ore in electric furnaces at Sorel yields a "nonspecification" steel and a slag that contains 70 percent TiO_2 . Estimates of reserves at Allard Lake range from 112 million tons of ore containing 32 percent TiO_2 to 200 million tons of ore containing 35 percent TiO_2 (Goodwin (100); Hammond (101)).

Titaniferous deposits occur west of St. Urbain, a small community approximately 8 miles north of Baie St. Paul, Charlevoix County. The deposits of ilmenite and minor amounts of included hematite occur in a small, oval, anorthosite mass that measures 9 by 18 miles. Rutile is locally abundant in some of the deposits. Ilmenite concentrate has been shipped from this area since 1924 and between 1924 and 1952 totaled 200,000 tons; maximum shipments were 76,540 tons in 1943. The richest material from the deposits ranges from 32.9 to 53.4 percent TiO_2 . The only resource estimates are from a company report on the Furnace and Coulombe deposits, where 1,300,000 tons of material is reported to have an average grade of 37 percent TiO_2 (Northern Miner, 103).

Ore from the Ivy mine in Beresford Township, Terrebonne County, contains ilmenite

TABLE 30.—Titanium resources of Canada, in short tons (all deposits are in the Province of Quebec)

Deposit	Titaniferous material	Grade, percent TiO_2	Contained TiO_2	Remarks
Allard Lake.....	¹ 112, 000, 000— ² 200, 000, 000	32. 0—35. 0	35, 840, 000— 70, 000, 000	Average grade of ore mined in 1952 was 35.0 percent TiO_2 . Company estimate.
Coulombe and Furnace (St. Urbain area).	³ 1, 300, 000	37. 0	481, 000	
Ivry.....	⁴ 1, 000, 000	⁵ 32. 0	320, 000	Grade is average of 4 analyses.
Saguenay River (Chicoutimi District).	⁶ 5, 000, 000	16. 7	835, 000	
Seven Islands area.....	⁷ 310, 000	15. 0—26. 0	72, 000	2 deposits.
Total.....	119, 610, 000—207, 610, 000 119. 6—207. 6 million tons		37, 548, 000—71, 708, 000 37. 5—71. 7 million tons	

¹ Hammond, Paul (101).

² Goodwin, W. M. (100).

³ Northern Miner (103).

⁴ Foreign Commerce Weekly (99).

⁵ Osborne, F. F. (104).

⁶ Dulioux, P. E. (97).

⁷ Faessler, Carl, and Schwartz, G. M. (98).

and included hematite and averages 30.3 to 33.2 percent TiO_2 . Large shipments were made from this mine during World War I and smaller ones between 1927 and 1935. Resources are estimated to be 1 million tons of "ore" (Foreign Commerce Weekly (99)).

In the Chicoutimi district bodies of ilmenite and magnetite occur on the north bank of the Saguenay River, about $1\frac{1}{2}$ miles west of St. Charles village. Lenses and dikes in anorthosite contain 5 million tons of "ore" having an average grade of 16.7 percent TiO_2 and 50.5 percent iron (Dulieux (97)).

Ilmenite-magnetite bodies in gabbro near the Bay of Seven Islands (also called Sept Iles Bay), on the northern shore of the St. Lawrence River approximately 320 miles north-east of Quebec City, have been described by Faessler and Schwartz (98). Along the St. Marguerite River a deposit one-half mile below the falls at Clarke City contains 10,000 tons of "ore" averaging 20 percent TiO_2 , and another deposit one-half mile above the falls contains 15 to 19 percent TiO_2 . Along the Rivière des Rapides, about three-fourths of a mile above its mouth, the Molson mine contains 300,000 tons of "ore" having 21 to 26 percent TiO_2 . Other deposits along this river include the Outarde Falls and the Gagnon deposits.

Sands along the St. Lawrence River near the mouth of the Great Natashkwan River are rich in heavy minerals and reportedly contain about 501,000 tons of black-sand concentrate. Although analyses of the concentrates are not given, the crude sand is known to contain 14.7 percent iron and 4.4 percent TiO_2 (MacKenzie (102)).

In the Province of Quebec numerous small deposits occur in Beauce, Chicoutimi, Hull, Lake St. John, Pontiac, St. Maurice, and Terrebonne Counties, in addition to titaniferous heavy sands in beaches along the north shore of the St. Lawrence River.

In the Province of Ontario, near Mine Centre, a narrow belt of ilmenite-magnetite deposits extends 14 miles along the north shore of Seine Bay and Bad Vermillion Lake. Flattened, lenticular bodies of ilmenite and magnetite that occur in hornblende gabbro contain 6.8 to 28.1 percent TiO_2 and 25.0 to 50.0 percent iron. During preliminary beneficiation tests it was impossible to obtain concentrates of either iron or titanium. Small deposits occur in Ontario, in Frontenac, Haliburton, Leeds, and Renfrew Counties and in the Nipissing district.

Small deposits of titaniferous sandstone have been reported from the Crownsnest Pass area of Alberta. Deposits of titaniferous magnetite at Steel Mountain, Newfoundland, contain 4 to 16 percent TiO_2 and 65 percent iron.

MEXICO

The principal titanium deposit in Mexico occurs at Pluma Hidalgo, in the State of Oaxaca. Republic Steel Co. announced in April 1954 acquisition of this large deposit of rutile in anorthosite and in December of the same year reported that the deposit contains 27,500,000 tons of rutile ore averaging 17.5 percent TiO_2 , equivalent to 4,812,000 tons of TiO_2 (Business Week (106)). The company reportedly is developing the deposit and plans to ship ore through Puerto Angel.

A deposit of ilmenite has been reported west of Victoria, the capital of the State of Tamaulipas. Titaniferous beach sands occur at Japútica, northwest of Acapulco, Guerrero. Ilmenite occurs also in Barranca del Rio Grande near Guadalajara, Jalisco. Small titaniferous deposits occur in Baja California, San Luis Potosi, and Sinaloa.

SOUTH AMERICA

ARGENTINA

In the Province of Buenos Aires, ilmenite- and magnetite-bearing beach sands along the Atlantic coast near Mar del Plata, Mar del Sur, Miramar, and Necochea contain 1 to 12 percent titanium and 2 to 23 percent iron. Accurate estimates of reserves are not available. In the province of Catamarca, west of Albogasta in the Sierra de Ancasti, a body of titaniferous magnetite in gabbro contains 17 percent TiO_2 , 66 percent FeO , 9 percent Fe_2O_3 , and 5 percent SiO_2 .

BRAZIL

Titanium ore has been produced from rutile deposits in the States of Ceara, Goiás, and Minas Gerais and from rutile- and ilmenite-bearing deposits of beach sand along the coast of Rio de Janeiro, Espirito Santo, and Baía. Exports of concentrates were begun in 1925 and from 1941 to 1954 totaled 14,683 tons of rutile concentrate and 23,446 tons of ilmenite concentrate. Accurate estimates of reserves are lacking.

In Ceara alluvial and residual deposits contain about 1 percent rutile that can be concentrated to a product of 88 to 96 percent TiO_2 . Because the region is dry, concentration of rutile is more difficult than in Goiás or Minas Gerais.

In Goiás stream gravels and beach deposits of the Araguaia, Paranaíba, and Tocantins Rivers contain rutile that can be obtained in concentrate of 92 to 97 percent TiO_2 . The rutile is recovered as a byproduct during mining of the deposits for gold and diamonds.

In Minas Gerais rutile containing 69 to 97 percent TiO_2 has been mined at Andrelandia,

Araxa, Ayuruoca, Bom Jardim, Lima Duarte, and Uberlandia. Most of the rutile occurs in residual or alluvial deposits overlying pegmatites and schist.

Beaches along the coast of Rio de Janeiro, Espirito Santo, and Bafa have deposits of heavy minerals that include ilmenite and rutile and have been described by Gillison (107). From limited, small-scale mining operations it was possible to produce ilmenite concentrate of 53 to 61 percent TiO_2 and rutile concentrate of 95 percent TiO_2 . Large-scale production from these deposits is difficult because the deposits are small and remote, good transportation is lacking, and the roads are generally in poor condition.

The best deposits in the State of Rio de Janeiro occur along the beach that extends southward 12 miles from the mouth of the Barra do Itabapoana River.

In the State of Espirito Santo the best deposits are, from south to north, at Boa Vista de Siri; at Maratayses; between Barra do Itapeirim and Guarapury; at Carapebus, Capubal, Jacareipe, and Boa Vista de Nova Almeida (all near Vitoria); near Ara Cruz; and near the mouth of the Rio Doce.

In the State of Baía the best deposits occur along the southern coast at Guaratiba and Comoxatiba, not far north of Caravellas.

The heavy-mineral concentrate of some beach deposits at Cunha, 30 miles south of Natal, contains 85 percent ilmenite and zircon.

BRITISH GUIANA

One sample of rutile from rutile-bearing placers in the Berbice district contained 95 percent TiO_2 .

CHILE

In 1944, 5 metric tons of rutile concentrate was reportedly produced at the Oxido de Titanio mine near La Seraba.

URUGUAY

Near Florida veins of titaniferous iron "ore" contain 12 to 23 percent TiO_2 and 45 to 56 percent iron.

AFRICA

ALGERIA

The Keddarans mine in the Palestro district reportedly produced 1,475 metric tons of titanium-zirconium concentrate in 1942, but no further information is available on this operation. Sand dunes near Biskra, north-eastern Algeria, are reportedly rich in ilmenite and magnetite. Ferromagnesian intrusive rocks

in various parts of the country are said to contain many bodies of ilmenite and magnetite.

BELGIAN CONGO

Ilmenite and rutile are commonly associated with alluvial deposits of gold and diamonds. Concentrations of rutile occur in alluvial deposits southwest of Lake Albert and in the Katanga region of southern Congo.

EGYPT

In Egypt a small annual production of ilmenite concentrate is reported from sands of the Nile Delta. Production totaled 7,390 tons from 1941 to 1954.

Sands of the Nile River Delta near Rosetta and Damietta contain in the richer deposits as much as 40 to 45 percent ilmenite, 20 to 25 percent titaniferous magnetite, and 10 to 12 percent zircon. At present, these sands are mined by hand and separated into concentrates of ilmenite, magnetite, zircon, garnet, and monazite at a dry mill in Alexandria. Reserves have been estimated at 15 million tons of black sand (Bureau of Mines (111)). Average grade of the deposits is approximately 25.7 percent TiO_2 , equivalent to 3,855,000 tons of contained TiO_2 .

A deposit of ilmenite, containing small amounts of included hematite, occurs in gabbro at Abu Ghalqua, near Wadi-Ranga, inland from the Red Sea coast. Preliminary estimates indicate several million tons of titaniferous material averaging about 47 percent TiO_2 (Amin (108)).

FRENCH CAMEROONS

In the French Cameroons production of rutile concentrate from 1941 to 1954 has been 16,900 tons. Although both residual and placer deposits are mined, the residual deposits are apparently richer in rutile and contain, in addition, ilmenorutile and magnetite. The richest regions are Banyo, Dschang, Eseka, Mbati, and Yaounde.

FRENCH EQUATORIAL AFRICA

In French Equatorial Africa (formerly French Congo) 7 tons of rutile concentrate was produced in 1950. The only available information on titaniferous occurrences indicates that rutile and ilmenite are very common in stream and residual deposits.

FRENCH WEST AFRICA

The only production of titanium ores in French West Africa has been from Senegal,

where beach sands yielded 68,995 tons of ilmenite concentrate in mining operations between 1941 and 1954.

DAHOMY

Near Couffo a residual clay overlying amphibolite contains pieces of ilmenite and averages about 35 percent TiO_2 . Residual deposits at Birmi, Djougou, and Gouboco contain abundant rutile that ranges from 93 to 96 percent TiO_2 in composition. In northwestern Dahomey the Mardaga deposit of ilmenite and hematite in gabbro averages about 15 percent TiO_2 .

IVORY COAST

Three deposits of beach sand along the coast between the mouth of the Cavalle and Sasandra Rivers average about 33 percent TiO_2 . At Bondoukou a residual sand overlying granite averages about 19 percent TiO_2 .

SENEGAL

Most of the ilmenite produced in Senegal has been obtained from sand deposits that occur along the coast for 150 miles southeast from Dakar. In this area the best deposits occur on the beach near Rufisque, in sand dunes between Joal and Palmarin, and on the beach at Casamance. The sand, as mined, generally contains 40 to 60 percent ilmenite and can be concentrated to a product of 52 percent TiO_2 .

Other deposits in Senegal include titaniferous heavy-mineral sands in the beaches between Dakar and St. Louis and placer deposits in the Kétiou-Kô River.

GOLD COAST

Little information has been published about titanium-bearing deposits of this area. In the Northern Territories titaniferous magnetite deposits reportedly occur at Pudo, near Naronogo. In southern Gold Coast ilmenite and rutile occur in diamond-bearing gravels of the Birim Valley.

MADAGASCAR

The only production of titanium ores in Madagascar was during World War I, when rutile was mined from quartz veins in western Ambatofinandrahana. Resources of titaniferous material in Madagascar are approximately 3,886,700 tons of material containing 1,045,000 tons of TiO_2 (table 31).

Near Betroka, on the southern part of the island, a deposit of ilmenite and hematite contains 3.9 million tons of "ore" averaging 27 percent TiO_2 (Lacroix (113)). A residual deposit of ilmenite and magnetite at Vongoha,

TABLE 31.—*Titanium resources of Madagascar, in short tons*

Deposit	Titaniferous material	Grade, percent TiO_2	Contained TiO_2
Betroka.....	¹ 3, 858, 000	27. 0	1, 042, 000
Vongoha.....	² 28, 700	1. 0–20. 0	2, 900
Total.....	3, 886, 700	.....	1, 044, 900

¹ Lacroix, Alfred, (113).

² Guigues, Jean, (112).

about 12 miles northeast of Miandirazon, contains 28,715 tons of material ranging in grade from 1 to 20 percent TiO_2 (Guigues (112)). Bodies of titaniferous magnetite are scattered throughout various parts of the island and have been described by Besaire (109).

On the island of Reunion, off the east coast of Madagascar, titaniferous sands contain as much as 24 percent TiO_2 in the heavy-mineral portion.

MOZAMBIQUE

Two deposits of ilmenite and magnetite occur in anorthosite and gabbro near Moatize. One deposit, the Mawili, contains 10 to 13 percent TiO_2 but cannot be treated to produce a high-grade ilmenite concentrate. The other deposit, the Kakanga, is closer to Moatize and although smaller than the Mawili can be treated to yield a nonmagnetic concentrate of 43 percent TiO_2 .

NYASALAND

In Nyasaland the sands and gravels of many streams contain abundant ilmenite. In the Port Herald Hills region primary deposits of ilmenite and magnetite occur over a large area. However, commercial development of these deposits is unlikely, because the individual bodies are too small and too widely separated from each other.

SIERRA LEONE

In Sierra Leone a large body of norite near Freetown contains layers of ilmenite and magnetite that average 15 to 18 percent TiO_2 . In preliminary beneficiation tests it was possible to obtain an ilmenite concentrate of 48 percent TiO_2 by means of magnetic separation. Near York and Hastings heavy-mineral deposits in the present-day beaches contain minerals derived from the norite body. In places, these deposits may analyze as much as 46.8 percent TiO_2 .

In the Nimi Koro Chieftdom near Fotingaia stream gravels of the Gbobore River yield an ilmenite-rich concentrate as a byproduct of placer mining for diamonds.

Prospecting of the Tonkolili River revealed that it contains 5½ pounds of ilmenorutile per cubic yard of gravel.

TANGANYIKA

In Eastern Upangwa, Tanganyika, large bodies of titaniferous magnetite occur in anorthosite and gabbro on Liganga Mountain. Resources have been estimated by Stockley (115, p. 270) at 1,344 million tons of "ore" averaging 12.7 percent TiO_2 . These estimates are not included in the total titanium resources of the world because: They were determined only by reconnaissance surveys; no indication is given of the amenability of this material to beneficiation; and the region is remote.

In the Uluguru Mountains of upper Mbakana Brook, blocks of "titanic iron ore" contain 25.3 percent TiO_2 .

UNION OF SOUTH AFRICA

Although the Union of South Africa has considerable resources of titaniferous material, very little production has been reported. Estimated resources are 25,428,000 tons of material containing 1,267,000 tons of TiO_2 (table 32). The large, titaniferous magnetite deposits of the Transvaal are not included in this figure, because only approximate estimates of these resources are available.

The largest titaniferous deposits occur in the Transvaal, where ilmenite-magnetite layers are associated with the Bushveld lopolith, a large, saucer-shaped body of ferromagnesian igneous rocks. Although the titanium-bearing layers contain 8 to 24 percent TiO_2 and 52 to 60 percent iron, they cannot be used as a source of ilmenite concentrate because most of the ilmenite is too fine-grained or occurs as small lamellae within magnetite and maghemite. Smaller bodies of similar composition occur at

Dwarsfontein No. 145, Brakfontein No. 219, and Kaffirskraaf and near Piet Retief. Although estimates by Wagner (116, p. 34) indicate that there are 2,376,600,000 tons of material containing 12.6 to 20.1 percent TiO_2 in the region, these figures have not been used in the compilation of world resources, because the figures are based to a large extent on geologic inference.

In central Natal, near the junction of the Tugela and Mabula Rivers, bodies of ilmenite and magnetite in gabbro and anorthosite contain 9 to 20 percent TiO_2 . Wagner (116, p. 40) has estimated the resource to be 16.8 million tons of material, but as these figures are based solely on maps of the deposit, they have not been included in this report.

In many places along the southeastern coast the beaches contain deposits of heavy minerals. At Umgababa the Titanium Corp. of South Africa has erected a small plant for mining and treating the sands and by early 1955 had shipped a small amount of concentrate. Reserves are estimated to be 25,300,000 tons of ore containing 2,200,000 tons of ilmenite having 48 to 52 percent TiO_2 , and 187,000 tons of rutile having 94 to 97 percent TiO_2 (Mining World, 114). Potentially worthwhile deposits are reported to occur also at Morgan Bay, approximately 40 miles northeast of East London.

In South-West Africa, 18 miles northeast of Karibib, a small deposit of rutile was mined in 1936 and 1937 and yielded 74 tons of concentrate containing 95 to 96 percent TiO_2 . Estimates of reserves in 1937 were 128,000 tons of "ore" averaging 4 percent TiO_2 (Bureau of Mines (110, p. 31)). Other titaniferous deposits in South-West Africa include rutile-bearing pegmatites in Otjisingati; veins of sphene at Khan-Grube, south of Arandis; and titaniferous pegmatites in the area around Rehoboth.

Along the west coast near Swakopmund sands contain abundant ilmenite but are not commercially attractive because of their re-

TABLE 32.—Titanium resources of the Union of South Africa, in short tons

Deposit	Titaniferous material	Grade, percent TiO_2	Ilmenite	TiO_2 in ilmenite	Rutile	TiO_2 in rutile	Total TiO_2	Remarks
Karibib	¹ 128, 000	4. 0					5, 000	Small production reported in 1954.
Umgababa.....	² 23, 300, 000	5. 0	2, 200, 000	1, 100, 000	170, 000	162, 000	1, 262, 000	
Total ..	25, 428, 000						1, 267, 000	

NOTE: Mineralized material in the Bushveld complex and in central Natal totals 2.4 billion tons, containing about 400 million tons of TiO_2 . Not economic.

¹ Bureau of Mines (110).

² Mining World (114).

mote location, their high magnetite content, and the lack of fresh water for beneficiation.

ASIA

CEYLON

Deposits of heavy-mineral sand are common along the coasts of Ceylon and are described and resources given in Ceylon, Records of Department of Mineralogy (118). At Pulmoddai on the northeast coast approximately 35 miles north of Trincomalee, black sands occur along $6\frac{1}{2}$ miles of beach and in places contain 74 percent ilmenite (62.5 percent TiO_2), 15 percent rutile, and 9 percent zircon. The deposit has been estimated to contain 5.6 million tons of black sand, of which 3.9 million tons is ilmenite. A similar deposit near Tirukkivil on the southeast coast, 45 miles south of Batticaloa, extends 3 miles along the beach and contains 560,000 tons of ilmenite. These resources are summarized in table 33.

On the west coast of Ceylon the black-sand deposits average about 10 to 30 percent ilmenite. The most important deposits occur at the following places: (1) Near the mouth of the Kelani River, north of Columbo; (2) near the mouth of the Kalu and Modaragam Rivers; (3) at Kudremalai Point, 40 miles south of Mannar; (4) at Negombo; and (5) at Induruwa on the southwest coast.

CHINA

Titaniferous magnetite deposits in the Luanping and Chen Te districts of Jehol Province, Manchuria, were mined by the Japanese during World War II and yielded 4,423 tons of ilmenite concentrate. One of these deposits occurs at Chi-chia-tzu ($41^{\circ}10' \text{ N.}$, $117^{\circ}42' \text{ E.}$) and consists of granular ilmenite and magnetite; the average grade is about 12 percent TiO_2 .

In western Formosa titaniferous sands occur in beaches, dunes, offshore barrier bars, and

stream deposits of the Coastal Plain. Resources are approximately 243,000 tons of heavy sand containing about 38 percent ilmenite (Chen (119, p. 18)). This is equivalent to about 27,000 tons of TiO_2 , assuming that the ilmenite contains 29.0 percent TiO_2 as shown in four analyses published by Chen (119).

INDIA

India, the largest supplier of titanium ores in the world before World War II, produced 2,817,770 tons of ilmenite concentrate and 10,779 tons of rutile concentrate in the period from 1941 through 1954. Estimates of resources are 131,143,000 tons of titaniferous material containing 38,036,000 tons of TiO_2 (table 34).

Beaches at Manavalkurichi and Quilon, Travancore, have been the major source of titanium ore. At Manavalkurichi the sand averages 50 to 70 percent ilmenite and can be concentrated to a product of 52 percent TiO_2 . At Quilon, the principal area of production since 1934, heavy minerals constitute 40 to 80 percent of the deposit and can be concentrated to a product of 60 percent TiO_2 . Reserves of the Travancore deposits have been estimated at 80 million tons of minable beach sands containing approximately 50 million tons of ilmenite and 2 million tons of rutile (Dunn and Morgan (120)). If the ilmenite is assumed to contain 60 percent TiO_2 and the rutile 95 percent TiO_2 , the deposits contain 31.9 million tons of TiO_2 .

Other beach deposits having concentrations of titaniferous minerals occur in the following places: On the Chowghat-Ponnani coast; in the Tinnevely district near the mouth of the Vaippar and Kallar Rivers; near Tranquebar on the Madras coast; and along the Malabar coast. Resources of these areas are given in table 34. Large deposits of ilmenite sand reportedly occur also in the Ratnargiri district of Bombay State.

Ilmenite and titaniferous magnetite are common in many primary deposits of the interior.

TABLE 33.—Titanium resources of Ceylon, in short tons

Deposit	Heavy sand	Contained ilmenite	Contained TiO_2	Remarks
Pulmoddai and Kokkilai	5,600,000	3,920,000	2,451,000	Amount of TiO_2 based on ilmenite analyses showing 62.5 percent TiO_2 . Reference gives only amount of ilmenite. Total amount of sand calculated from analyses. TiO_2 content determined as above.
Tirukkivil	800,000	560,000	349,000	
Total	6,400,000	4,480,000	2,800,000	

¹ Ceylon, Department of Mineralogy (118).

TABLE 34.—*Titanium resources of India, in short tons*

Deposit	Titaniferous material	Grade, percent		Contained TiO ₂	Remarks
		Ilmenite	TiO ₂		
Chowghat; Ponnani coast sands.....	¹ 1, 026, 000	² 49. 2		262, 000	Most promising area is near Blangad.
Dhalbhum subdivision of Singhbhum....	³ 1, 120, 000	.....	⁴ 28. 0	314, 000	
Mysore State; titaniferous magnetite deposits:					
Chokkonhalli, Gobalihalli, Jambur, and Tagadur, in Nuggihalli schist belt.	⁵ 10, 090, 000	.....	10. 2	1, 029, 000	
Devaranarasipur and Bhadravati.	⁵ 333, 000		11. 0	37, 000	Important producer.
Ubrani and Chilanhalli, in Channagiri Taluk.	⁵ 38, 438, 000	.....	11. 6	4, 459, 000	
Tranquebar, Tanjore district, Madras State:	¹ 100, 000	² 50. 5	.....	26, 000	
Travancore, beach deposits.....	⁶ 80, 000, 000	.....	39. 9	31, 900, 000	
Vaippar and Kallar Rivers, Tinnevely district.	¹ 36, 000	² 49. 5	.....	9, 000	
Total.....	131, 143, 000	.....	.....	38, 036, 000	

¹ Bureau of Mines (117, pp. 21-24).² Ilmenite assumed to contain 52 percent TiO₂.³ Dunn, J. A., and Dey, A. K. (120, pp. 117-184).⁴ Krishnan, M. S., and Roy, B. E. (121).⁵ Radhakrishna, B. P. (124).⁶ Calculated from Dunn, J. A., and Morgan, J. W. (120, pp. 6-8).

Deposits occur in Singhbhum and Mayurbhanj; near Gulimcherla in the Nellore district of Madras; in the Channagiri Taluk of Mysore; in the Nuggihalli schist belt of the Channarayapatna Taluk; in Bihar near Supur; and in the foothills northwest of Manbazar.

Rutile occurs in the Naurnal district of Patiala, Punjab; south of Rajputana; in the mica schist of Singhbhum; and in the kyanite rocks of Dhalbhum and Mayurbhanj.

INDOCHINA

Many river and beach sands in Indochina contain appreciable amounts of ilmenite, especially on the Bay of Camranh in South Annam, where large quantities of titaniferous sand reportedly occur. None of the deposits has been investigated in detail.

JAPAN

From 1925 to 1946 Japan produced 28,171 tons of titanium concentrate containing 26 to 45 percent TiO₂. The largest output was during World War II. At present the Japanese are making a high-titania slag for use in the titanium-metal industry; production of slag in 1953 and 1954 totaled 4,655 tons.

The most important sources are titaniferous iron sands that are common at numerous places in Japan and are especially abundant in northern Honshu and southern Hokkaido. Although some sources indicate that resources of these iron sands are as much as 200 million tons,

recent work has shown that there are about 41,632,000 tons of iron sand averaging about 8.5 percent TiO₂ (Staatz (123, pp. 3, 12)), equivalent to 3,539,000 tons of TiO₂.

Iron-sand mines were operated principally as a source of titanium ore in Hokkaido Prefecture on the island of Hokkaido; in Fukushima, Ibaraka, and Shimane Prefectures of Honshu; and in Ehime and Kochi Prefectures of Shikoku. The principal primary deposit, the Kengamine mine in Fukushima Prefecture of Honshu, contains titaniferous magnetite "ore" in gabbro.

KOREA

Titanium ore was mined in Korea only during World War II, when small amounts of ilmenite concentrate were produced by the Japanese.

On the island of So-Yonpyong-do, 52 miles northwest of Inchon, a deposit of ilmenite and magnetite occurs in pyroxenite and gabbro. Estimates show 2,535,000 tons of "ore" averaging 20 percent TiO₂, 50 percent iron, and 0.24 percent vanadium; this is equivalent to 507,000 tons of TiO₂ (Yagyū (125, p. 179)). By magnetic separation or flotation it is possible to produce an ilmenite concentrate containing 47 percent TiO₂, 35 percent iron, and 0.07 percent vanadium, and an iron concentrate containing 64 percent iron, 8 percent TiO₂, and 0.34 percent vanadium.

Other titaniferous bodies are small and low-grade. On Shoenpeito Island an ilmenite-magnetite body averages 21 percent TiO₂. A

deposit at Porumdo contains 25 percent ilmenite, accompanied by small amounts of magnetite. At Komasan and Konan-san titaniferous deposits occur in anorthosite, and one at Kansan-ri occurs in veins cutting gneiss.

Placer deposits abound in Korea and commonly have a high content of ilmenite; however, development of most of these placers would necessitate disrupting the farming in the valleys where they occur.

MALAYA

Ilmenite concentrate shipped from Malaya from 1947 to 1954 totaled 231,804 tons. Estimates of titanium resources are not available for Malaya.

All the ilmenite is produced as a byproduct of placer mining for tin minerals and comes chiefly from the States of Perak and Selangor, the principal tin-mining areas. The ilmenite is separated from "amang," the residue or tailing that remains after the tin minerals are extracted from the sands and gravels. Only a small part of the available amang is treated to recover ilmenite. The ilmenite concentrate usually contains 52 to 54 percent TiO_2 .

TURKEY

Near Sile, Istanbul, a small deposit of black sand on the shore of the Black Sea contains 32.6 percent ilmenite, 32.4 percent magnetite, and 18.7 percent zircon.

EUROPE

BULGARIA

Near Burgas, Bulgaria, on the west shore of the Black Sea, black sands contain 10 percent TiO_2 and 50 percent iron. The deposits cover an area of 8 square miles and have an average thickness of 3 to 7 feet.

FINLAND

The only producing titanium mine in Finland is at Otanmäki, where during 1954 production was approximately 175,000 tons of magnetite concentrate and an unreported amount of ilmenite. Reserves are estimated to be 50 million tons of ore, containing 6,750,000 tons of TiO_2 (Stigzelius (131)). The deposit, in central Finland south of Oulunjärvi, was discovered in 1938. The deposit of ilmenite and magnetite in a deformed amphibolite averages 12 to 15 percent TiO_2 and 35 percent iron. The annual production from this deposit has been planned at 175,000 tons of magnetite concentrate and 75,000 to 100,000 tons of ilmenite concentrate containing approximately 47 percent TiO_2 .

Small deposits of titaniferous magnetite are common at many places in Finland. The better known deposits occur at the following places: Near Attu on the island of Runholm, parish of Parainen; at Kitula, village of Kirju, parish of Suomusjärvi; at Riuttamaa, parish of Köyliö; at Susimäki, estate of Jonkka, parish of Vampula; and at Vuorijärvi, parish of Kuolajärvi.

GERMANY

On the island of Wangeroog in the Frisian Islands heavy-mineral-bearing sands contain 48 percent ilmenite and 12 percent magnetite. In 1953 the black sands on the isle of Sylt in the Frisian Islands were mentioned as a possible ore of titanium, although in 1871 these same sands were treated unsuccessfully for their iron content.

HUNGARY

In the Bükk Mountains southeast of Szarvasko bodies of titaniferous magnetite occur in gabbro and peridotite and in places may average as much as 23.2 percent TiO_2 . Analyses of titaniferous magnetite from these deposits show 32 to 41 percent TiO_2 and 38 to 48 percent iron.

ITALY

Iron-bearing titaniferous beach sands have been mined along the coast of the Tyrrhenian Sea between Civitavecchio and Salerno. The following concentrates were obtained from these sands: (1) A titanium concentrate containing 35 percent TiO_2 and 24 percent iron; (2) an iron concentrate containing 5.8 percent TiO_2 and 62 percent iron; and (3) a zircon concentrate containing 40 percent zircon. Iron sands occur also on the east coast, at Margherita di Savoia in Foggia.

NORWAY

Norway is the most important producer of titaniferous concentrates in Europe, having produced in the period from 1941 to 1954, 1,320,203 tons of ilmenite concentrate and 823 tons of rutile concentrate. Resources are approximately 166,172,000 tons of titaniferous material, containing 25,703,000 tons of TiO_2 . The tonnages of individual deposits are summarized in table 35.

The Ekersund-Soggendal area, on the southwest coast south of Stavenger, is the most important commercial area in the country. In this region ilmenite-magnetite and ilmenite-hematite bodies occur in anorthosite and gabbro at the Haaland, Hegdal, Koldal, Kyland, Lakesdal, Storgangen, and Tellnes deposits. At the Storgangen deposit Titan Co. A/S mines ore that averages 17 percent TiO_2 and concentrates it to an ilmenite product of 43 percent

TABLE 35.—*Titanium resources of Norway, in short tons*

Deposit	Titaniferous material	Grade, percent TiO ₂	Contained TiO ₂	Remarks
Lakesdal	¹ 276, 000	35. 0	97, 000	In Ekersund-Soggendal area.
Rödsand	² 3, 307, 000	6. 0	198, 000	Concentrate of 44 percent TiO ₂ can be produced.
Selvåg (Lofoten and Vesteraalen Islands).	³ 16, 534, 000	4. 0	661, 000	
Solnördal	³ 2, 756, 000	14. 0	386, 000	
Storgangen	² 33, 069, 000	17. 0	5, 622, 000	Important producer, in Ekersund-Soggendal area. Concentrate of 44 percent TiO ₂ produced.
Tellnes	⁴ 110, 230, 000	17. 0	18, 739, 000	Newly discovered deposit in Ekersund-Soggendal area.
Total	166, 172, 000	-----	25, 703, 000	

¹ Thornton, W. M. (122).² Magnusson, N. H. (128, pp. 1021-1024).³ Imperial Mineral Resources Bureau (127).⁴ Mining World (129, p. 79).

TiO₂ and 35 percent iron. Reserves are about 33 million tons, equivalent to about 5.6 million tons of TiO₂ (Magnusson (128)). In the latter half of 1955 the same company announced discovery in this same area of the Tellnes deposit, containing 110 million tons of ore, equivalent to about 18.7 million tons of TiO₂ (Mining World (129)). The Lakesdal deposit also in this area, contains 276,000 tons of titaniferous material having 35 percent TiO₂ (Thornton (132)).

In the vicinity of Rödsand in Nordmøre titaniferous magnetite bodies containing 6.0 to 7.5 percent TiO₂ and 35 percent iron were supposedly being developed in 1955. It is indicated that ilmenite concentrate of 44 percent TiO₂ and 35 percent iron can be produced. Resources are estimated to be 3.3 million tons of "ore," averaging 6 percent TiO₂ (Magnusson (128)).

The only commercial deposit of rutile in Norway occurs on the southeast coast at Kragerö. Dikes of kragerite, a rock composed mostly of albite and rutile, contain about 5 to 10 percent rutile.

Deposits of titaniferous magnetite are numerous on the Lofoten and Vesteraalen Islands. At Selvog 1 of these deposits contains 16.5 million tons of titaniferous material averaging 4 percent TiO₂ and 35 percent iron (Imperial Mineral Resources Bureau (127)).

Elsewhere in Norway titaniferous deposits are common. On the south side of the Lia Mountains north of Storfjord the Soholt deposit in Örskoug averages about 14 percent TiO₂ and 50 percent iron. On the north side of the mountains near Skodje the Soldnördal deposit includes an estimated 2.76 million tons of "ore" containing 12 to 15 percent TiO₂ and 35 to 48 percent iron (Imperial Mineral Resources Bureau (127)). Preliminary tests showed that

ilmenite concentrate of 44 percent TiO₂ and 35 percent iron could be obtained.

PORTUGAL

The production of ilmenite concentrate from Portugal has totaled 5,552 tons from 1941 to 1954, inclusive.

Ilmenite is obtained as a byproduct of the mining for tin minerals from valley placers north of Belmonte.

Sands of São Torpes beach near Sines contain as much as 40 percent TiO₂ in the richer heavy-mineral layers.

SPAIN

In Spain ilmenite concentrate has been produced from Coruna and Huelva Provinces; shipments from 1941 to 1954 totaled 7,240 tons of concentrate. Estimates of resources are not available.

In Coruna Province ilmenite-bearing beach sands near the mouth of the Allones River average about 10 percent TiO₂ and can be treated to yield an ilmenite concentrate of 50 to 52 percent TiO₂. In Huelva Province a deposit that was discovered near Almonte in 1948 reportedly yielded a small amount of titanium concentrate in 1949.

Titanium-bearing beach sands are reported to occur also in Corino, northern Coruna Province; along the Sil River in Orense Province; and in beaches on the Balearic and Canary Islands.

A deposit of titaniferous magnetite reportedly occurs in the foothills of the Pyrenees near Olot, north of Barcelona.

SWEDEN

Although titaniferous deposits are common in Sweden, there has been only a small, un-

TABLE 36.—*Titanium resources of Sweden, in short tons*

Deposit	Titaniferous material ¹	Grade, percent TiO ₂	Contained TiO ₂	Remarks
Järvsö (Kramsta)	27, 557, 000	5. 0	1, 378, 000	Numerous, low-grade deposits. Remote location. Best ilmenite concentrate contains 20 percent TiO ₂ . Fine-grained intergrowths of magnetite and ilmenite make it impossible to obtain ilmenite concentrate. No ilmenite concentrate. Numerous, small deposits.
Ruotevare	33, 069, 000	11. 0	3, 638, 000	
Taberg	165, 345, 000	6. 0	9, 921, 000	
Ulvön	22, 046, 000	8. 0	1, 764, 000	
Total	248, 017, 000	-----	16, 701, 000	

¹ Magnusson, N. H. (128, pp. 1021-1024).

specified production of titanium concentrate. The total resources, as determined from estimates made by Magnusson (129) on individual deposits, are 248.0 million tons of material containing 16.7 million tons of TiO₂. The grade and tonnage of individual deposits are summarized in table 36.

In Hälsingland the Järvsö deposit in Kramsta near the Järvsö Station consists of low-grade titanomagnetite deposits in gabbro and averages 5 percent TiO₂ and 20 percent iron. Only about 3.6 percent of the titaniferous material can be extracted in an ilmenite concentrate containing 38 to 40 percent TiO₂. Resources are approximately 27.6 million tons of "ore."

The Ruotevare deposit near Kvikkjokk contains lenses of ilmenite and magnetite in anorthosite and averages 11 percent TiO₂ and 46 percent iron. Preliminary tests showed that the best titanium concentrate contained only 14 to 20 percent TiO₂. Resources are 33.1 million tons of titaniferous material.

In Småland a titaniferous deposit at Taberg, about 7 miles south of Jönköping, occurs in an

olivine norite. Because the titanium occurs only in fine-grained ilmenite that is included within magnetite, titaniferous concentrate cannot be produced. The average grade of the deposit is 6 percent TiO₂ and 32 percent iron; resources are 165.3 million tons of titaniferous material.

Numerous deposits of titaniferous magnetite occur on the Ulvö Islands in the archipelago of Ångermanland. The best deposits occur on South Ulvön (Södra Ulvön), where magnetite and ilmenite lenses average 8 percent TiO₂ and 53 percent iron. Resources are estimated at 22.0 million tons of titaniferous material.

U. S. S. R.

Although deposits of titaniferous material are common at many places in Soviet Russia, information is difficult to obtain, because much of the available literature is in Russian and for the most part earlier than 1940. Estimates of resources are 145.6 million tons of titaniferous material containing 14.5 million tons of TiO₂ (table 37).

TABLE 37.—*Titanium resources of U. S. S. R., in short tons*

Deposits	Titaniferous material	Grade, percent TiO ₂	Contained TiO ₂	Remarks
Pudozhgora (Kola Peninsula)	¹ 406, 000	10. 0	41, 000	Deposit contains 893,000 tons of ilmenite in sands.
Ukraine deposits Sea of Azov sands at:				
Belosarajskaja	¹ 331, 000	35. 0	116, 000	
Ganzukovskaja	8, 000	14. 2	1, 000	
Nogajskaja	11, 000	33. 2	4, 000	
Portovaja	2, 000	37. 6	1, 000	
Gakovske and Rudno-Gakovske (Zitomir district)	-----	-----	¹ 492, 000	
Ural Mountains	² 144, 880, 000	-----	13, 835, 000	
Total	145, 638, 000	-----	14, 490, 000	

¹ Gmelin-Institut (1936).² See table 38.

The largest titaniferous deposits occur in the Ural Mountains, where estimates of resources are 144.9 million tons of material, containing 13.8 million tons of TiO_2 . The above estimates are based on a compilation from various sources (see table 38).

In the Ural Mountains some of the larger deposits have commercial importance; these include the Kusa deposit, also referred to as the Kusin, Kusinska, or Magnitnoye deposit. The Kusa deposit lies in the Zlatoust mining area of the Ilmen Mountains, approximately 8 or 9 miles west of the city of Kusa. The ilmenite-magnetite ore occurs as dikes in gabbro and contains an average of 14.2 percent TiO_2 and 54 percent iron. Products obtained include an ilmenite concentrate containing 42 percent TiO_2 and 37 percent iron and an iron concentrate containing 7 percent TiO_2 and 64 percent iron. The Kopanskoye or Satkinskaya Dacha deposit occurs in the same general area and is 20 miles southwest of Zlatoust and 12 miles northeast of Satka. "Veins" of ilmenite and magnetite in gabbro average about 11 percent TiO_2 . The deposit was not considered commercially attractive in the late 1930's because the "ore" is heterogeneous and requires extensive hand sorting. Other deposits in the Ural Mountains are tabulated in table 38.

The Kola Peninsula is another area in Russia that contains numerous titaniferous deposits. In the Pudozhgora district on the east shore of Lake Onega, titaniferous magnetite deposits average 9 to 11 percent TiO_2 and 30 to 45 percent iron. Resources are 406,000 tons of titaniferous material averaging 10 percent TiO_2 (Gmelin-Institut (126)). In the area near Kirovsk many active, large apatite mines contain as much as 2 percent sphene and 2 percent titaniferous magnetite. Other titaniferous deposits in the Kola occur near Koybory, near Okhto-Kanda, at Valimaki, and near Yurkino.

In the Ukraine titanium deposits occur near Gatzkova in the Voldarsky district approximately 190 miles north of Odessa. In the Zitimir district near Gakovske and Rudno-Gakovske ilmenite- and kaolin-bearing sands contain a total of about 984,000 tons of ilmenite, equivalent to approximately 492,000 tons of TiO_2 (Gmelin-Institut (126)). Black sands of the Sea of Azov at Belosarajskaja, Ganzukovskaja, Nogajskaja, and Portovaja contain 14 to 38 percent TiO_2 ; resources are 352,000 tons of heavy sands, equivalent to 122,000 tons of TiO_2 (Gmelin-Institut (126)). Titanium-bearing sands in the Mius (Miusliman) Delta contain 25 to 65 percent magnetite and titanomagnetite. Sands near Chutor Najdenovka contain 24 to 31 percent TiO_2 .

In the Caucasus a deposit at Elizauetpol near Alabashly reportedly contains 1 to 14 percent TiO_2 .

In the Kirgiz steppes east of the Caspian Sea in Central Asia titaniferous magnetite in the western part of Tur-achyr contains a maximum of 15.3 percent TiO_2 .

Titaniferous magnetite deposits are reported to occur in the Nerchinski mining district of Trans Baikal.

OCEANIA

AUSTRALIA

Australia, the principal source of rutile in the world, has in the period from 1941 through 1954 produced 286,780 tons of rutile concentrate and 119,172 tons of ilmenite concentrate. Resources of beach and placer deposits, as of 1951, are 2,689,000 tons of rutile and 4,289,000 tons of ilmenite, equivalent to 4,784,000 tons of TiO_2 . Total resources of Australia, including primary deposits, are estimated to be 14.4 million tons of titaniferous material containing 5.2 million tons of TiO_2 . These resources are summarized in table 39 and are taken prin-

TABLE 38.—Titanium resources of Ural Mountain area, U. S. S. R.,¹ in short tons

Deposit	Titaniferous material	Grade, percent TiO_2	Contained TiO_2	Remarks
Bilimbaevskoye.....	3, 400, 000	3. 5	119, 000	Mostly inferred.
Chernorechenskoye.....	770, 000	13. 0	100, 000	2 deposits.
Kachkanar.....	34, 200, 000	3. 5	1, 197, 000	Mostly inferred.
Kopanskoye.....	17, 600, 000	11. 0	1, 936, 000	Do.
Kusa (Kusin, Kusinska, or Magnitnoye).	66, 800, 000	14. 2	9, 486, 000	Ilmenite concentrate contains 42 percent TiO_2 .
Pervoural'skoye.....	11, 000, 000	3. 0	330, 000	Mostly inferred.
Spornoe.....	110, 000	6. 5	7, 000	
Yubryshka Mountains.....	11, 000, 000	6. 0	660, 000	All inferred.
Total.....	144, 880, 000	-----	13, 835, 000	

¹ Information from Gmelin Institut (127) and from Panteleev, H. A., and Malyshev, I. I. (131, pp. 221-235).

TABLE 39.—*Titanium resources of Australia, in short tons*

State	Primary deposits		Beach deposits			All deposits	
	Titaniferous material	TiO ₂	Rutile	Ilmenite	TiO ₂	Titaniferous material	TiO ₂
New South Wales ¹	2, 264, 000	207, 000	568, 000	360, 000	726, 000	4, 037, 000	933, 000
Queensland ²			2, 107, 000	3, 325, 000	3, 731, 000	7, 784, 000	3, 731, 000
Tasmania ³				50, 000	26, 000	50, 000	26, 000
Western Australia ⁴	1, 680, 000	213, 000	14, 000	554, 000	301, 000	2, 576, 000	514, 000
Total.....	3, 944, 000	420, 000	2, 689, 000	4, 289, 000	4, 784, 000	14, 447, 000	5, 204, 000

¹ From table 40.² From table 41.³ Gardner, D. E. (138).⁴ From table 42.

cipally from a comprehensive report by Gardner (138) on the titanium deposits of Australia.

In 1952 the principal mining activity was along the east coast from North Stradbroke Island, Queensland, to Swansea Bay, New South Wales; additional small production was reported in 1949 and 1950 from sands of Western Australia. Rutile obtained from the east coast deposits is marketed throughout the world, but the ilmenite cannot be sold because it contains as much as 7 percent Cr₂O₃, thereby making it unacceptable for use in manufacturing pigment. Investigations in 1948 indicated that 60 percent of the ilmenite concentrate could be treated to yield a product containing only 0.25 to 0.6 percent Cr₂O₃.

The heavy-mineral concentrate from the black-sand deposits along the east coast of New South Wales and Queensland averages 34 percent ilmenite, 24 percent rutile, 39 percent zircon, and 3 percent other minerals (garnet, monazite, tourmaline, leucoxene).

NEW SOUTH WALES

In New South Wales mining for rutile and ilmenite was begun in 1934 at Byron Bay and by 1955 was carried out at many places along approximately 45 miles of the coast extending south from the Queensland border. Production has recently been reported also from Swansea. The location and resources of titaniferous deposits in New South Wales are shown in table 40, which includes some of the major deposits along the coast. In the interior several small bodies of titaniferous magnetite occur in sandstone near the junction of the Williams and Karuh Rivers. According to reconnaissance surveys, the largest deposit contains about 100,000 tons of TiO₂. Total resources of this area are 2,263,500 tons of titaniferous material containing 2 to 16 percent TiO₂, equivalent to about 207,000 tons of TiO₂ (Imperial Mineral Resources Bureau (140)).

TABLE 40.—*Titanium resources of New South Wales, Australia, in short tons*

Deposit	Heavy minerals	Grade, percent heavy minerals	Rutile	Ilmenite	Contained TiO ₂
Tweed Heads to Fingal Point.....	53, 200	13. 7	14, 800	11, 400	20, 000
Fingal Point to Cudgen Headland.....	71, 200	18. 8	25, 000	15, 800	31, 900
Cudgen Headland to Norries Head.....	716, 800	17. 2	250, 200	152, 000	316, 700
Norries Head to Hastings Point.....	212, 500	14. 2	63, 800	44, 800	83, 900
Hastings Point to Potts Point.....	89, 700	29. 3	27, 800	17, 300	35, 400
Potts Point to Brunswick Heads.....	216, 900	18. 8	76, 400	44, 000	95, 500
Brunswick Heads to Cape Byron.....	156, 000	28. 8	40, 200	28, 100	52, 800
Cape Byron to Broken Head.....	231, 200	10. 7	62, 200	41, 700	80, 800
Broken Head to Lennox Head.....	25, 600	14. 5	7, 200	4, 500	9, 100
Northwest of Port Stevens.....	2, 263, 500				207, 000
Total.....	4, 036, 600		567, 600	359, 600	933, 100

NOTES: The deposit northwest of Port Stevens is a titaniferous magnetite. All the other deposits are beach sands.

Titanium content calculated by assuming that the rutile contains 95 percent TiO₂ and the ilmenite 52 percent TiO₂.

Information on beach sand deposits is from Gardner, D. E. (138).

Information on titaniferous magnetite deposit is from Imperial Mineral Resources Bureau (140).

QUEENSLAND

In Queensland rutile and ilmenite were first produced in 1941, and by 1953 sands were mined at various places along 50 miles of coast-line extending northward from the border of New South Wales. Deposits of potentially commercial importance occur as much as 180 miles north of the border. Most of the deposits listed in table 41 are high-grade beach deposits, some of which are mined at present. A large deposit in the dunes on the main part of North Stradbroke Island is not mined at present because of its low grade, but it represents an important potential supply.

SOUTH AUSTRALIA

In South Australia residual deposits of rutile occur in the vicinity of Blumberg, Williams-town, and Mount Crawford. Near Mount Jagged small deposits of rutile average 5 percent TiO_2 . At Mount Painter small quantities of sphene and rutile occur within a granitic rock. At Radium Hill titaniferous iron "ore" comprises a large part of the "ore shoots" and contains 60.7 percent TiO_2 . Lenses of rutile occur in schist at Yankalilla, 40 miles southwest of Adelaide.

TASMANIA

On King Island, Tasmania, a terrace deposit at Naracoopa that yielded 606 tons of ilmenite concentrates in 1933 contains 50,000 tons of ilmenite, abundant cassiterite, and minor amounts of gold, monazite, zircon, and molybdenite (Gardner (138, p. 23)).

VICTORIA

Deposits in the valley of the Acheron River, Victoria, average 40 pounds of heavy minerals

per cubic yard of earth and contain about 180,000 tons of heavy minerals. Ilmenite from this deposit contains 52 to 55.5 percent TiO_2 and was obtained in concentrates of 84.5 percent purity (Gardner (138, p. 23)). At Cape Everard, a low-grade beach deposit contains 2,200 tons of heavy minerals, containing 62 percent ilmenite and 11 percent rutile (Gardner (138, p. 23)). These resources for Victoria are not included in the resource table for Australia because no information is given as to titanium content of the Acheron deposit and the Cape Everard deposit is too small.

WESTERN AUSTRALIA

In Western Australia the production of ilmenite concentrate began in 1949 and during 1949 and 1950 totaled only 17 tons. Estimates of resources, as given by Gardner (138, pp. 24-25), are summarized in table 42. Except for the ridge of titaniferous magnetite and hematite at Gabanintha, all of the deposits are beach and dune placers.

NORTHERN TERRITORY

In Port Essington, Northern Territory, heavy-mineral deposits on beaches near Record Point and Reef Point contain black sands having abundant titaniferous minerals. Beaches on Bowen Bay, Bathurst Island, near Cape Fourcroy, contain 40 percent ilmenite and 31 percent rutile.

NEW ZEALAND

Titanium occurs in iron-bearing black sands along the Taranaki coast of North Island and at various places on South Island. Resources have been estimated only for parts of North Island. The more important, potentially val-

TABLE 41.—Titanium resources of Queensland, Australia, in short tons

Deposit	Heavy minerals	Grade, percent heavy minerals	Rutile	Ilmenite	Contained TiO_2
Indian Head, Fraser Island.....	¹ 97, 400	65. 0	16, 500	54, 500	44, 000
North Stradbroke Island, Beaches near north end.....	² 672, 000	12. 4	174, 700	309, 100	326, 700
North Stradbroke Island, dunes in main part of island.....	² 6, 720, 000	3. 0	1, 814, 400	2, 889, 600	3, 226, 300
Surfers' Paradise to North Burleigh.....	² 69, 800	16. 7	24, 900	16, 900	32, 500
North Burleigh to Burleigh.....	² 119, 800	12. 6	42, 200	28, 800	55, 100
Burleigh.....	² 14, 100	15. 7	3, 500	5, 500	6, 200
Palm Beach.....	² 52, 600	19. 2	18, 800	11, 800	24, 000
Flat Rock Creek.....	² 8, 100	13. 7	2, 900	1, 800	3, 700
Tugun-Bilinga.....	² 30, 000	17. 9	9, 500	7, 500	12, 900
Total.....	7, 783, 800	-----	2, 107, 400	3, 325, 500	3, 731, 400

NOTE: All deposits are in sand. Titanium content estimated by assuming rutile contains 95 percent TiO_2 and ilmenite contains 52 percent TiO_2 .

¹ Connah, T. H. (134, pp. 223-245).

² Gardner, D. E. (133).

TABLE 42.—*Titanium resources of Western Australia, Australia, in short tons*

Deposit	Heavy minerals, tons	Rutile, tons	Ilmenite, tons	Contained TiO ₂ , tons	Remarks
Bunker's Bay	¹ 224, 000	3, 800	163, 700	88, 700	Ancient and modern beaches. Beach and dune deposits have been mined.
Cheyne Bay	¹ 44, 800	1, 300	31, 600	17, 600	
Doubtful Island Bay	¹ 44, 800	1, 300	31, 600	17, 600	Beach deposits.
Minninup	¹ 224, 000	200	22, 400	11, 900	Do.
Wonnerup	¹ 358, 400	7, 200	304, 600	165, 200	Ancient beach deposit. Titaniferous magnetite deposit. Grade is 12.7 percent TiO ₂ .
Gabanintha	² 1, 680, 000	-----	-----	213, 400	
Total	2, 576, 000	13, 800	553, 900	514, 400	

NOTE: Titanium content of beach sands has been calculated by assuming that the rutile contains 95 percent TiO₂ and the ilmenite 52 percent TiO₂.

¹ Gardner, D. E. (138).

² Imperial Mineral Resources Bureau (149).

uable deposits total 247.4 million tons of iron sand containing 50.4 million tons of titanomagnetite, equivalent to about 4.6 million tons of TiO₂ (table 43). Other low-grade deposits, or deposits for which only reconnaissance surveys have been made, are not included in the above total.

The iron sands on North Island occur at various places along the coast of Taranaki, from Wanganui northward to Kaopara Heads, a distance of about 330 miles. The deposits that at present offer the best opportunity for development occur at Patea, New Plymouth, Waitara, and Wanganui. The resources of these occurrences are tabulated in table 43. Other deposits mentioned by Fyfe (137) include ancient beach and dune deposits near New Plymouth that contain an estimated 200 million tons of titanomagnetite. Utilization of these deposits appears unlikely, because they

occur on good farmland, hence their resources are not included in the New Zealand total.

Between Mokau and Muriwai is 251 million tons of titanomagnetite in deposits containing over 20 percent titanomagnetite and 297 million tons in deposits containing less than 20 percent titanomagnetite (Fyfe, (137)). However, these deposits also are not included in the New Zealand total for the following reasons: All of the estimates are based on reconnaissance surveys; most of the larger individual deposits are of low grade; and most of the material is in inaccessible areas.

Analyses of the opaque minerals in the iron sands on North Island show 8 to 10 percent TiO₂, 53 to 60 percent Fe, and 0.3 to 0.5 percent V₂O₅. However, this material cannot be used as a source of titanium concentrate because the titanium does not occur in large grains of

TABLE 43.—*Titanium resources of New Zealand, in short tons*

Deposit	Heavy sand	Titanomagnetite	Grade of titanomagnetite, percent TiO ₂	Contained TiO ₂	Remarks
Mouth of Waiwakaiho River, Fitzroy, New Plymouth.	¹ 1, 255, 000	560, 000	8. 57	48, 000	Beach and dune deposits.
Mouth of Patea River	² 50, 400, 000	15, 680, 000	³ 9. 60	1, 505, 000	Terrace, beach, and dune deposits.
Beach west of mouth of Waitara River.	⁴ 35, 245, 000	8, 609, 000	9. 0	775, 000	Terrace, beach, and dune deposits. Grade of titanomagnetite is assumed.
Wanganui	⁵ 160, 535, 000	25, 544, 000	9. 0	2, 299, 000	Beach and dune deposits. Grade of titanomagnetite is assumed.
Total	247, 435, 000	50, 393, 000	-----	4, 627, 000	

¹ Hutton, C. O. (179).

² Mason, Brian (141).

³ Wylie, A. W. (112).

⁴ Beck, A. C. (133).

⁵ Fleming, C. A. (156).

ilmenite or rutile. Most of the titanium occurs as follows: (1) In the lattice of magnetite; (2) in fine-grained intergrowths of ilmenite in magnetite; and (3) in the lattice of hematite that is included in magnetite.

On South Island are many small deposits of iron sand that could yield ilmenite concentrate, as they contain separate, individual grains of ilmenite and magnetite. Detailed information about resources is lacking.

CHAPTER 4. PROSPECTING, MINING, AND BENEFICIATION

PROSPECTING *

To prospect efficiently for titaniferous deposits, an investigator must know what type of deposit is likely to occur in the area being investigated. The outcome of the prospecting program will depend then, in part, on proper selection of an investigative procedure best suited for the kind of deposit desired.

PROSPECTING FOR PRIMARY DEPOSITS

The rutile in primary deposits is generally an accessory mineral and is distributed so randomly that no generalized procedure can be outlined for prospecting. Primary ilmenite deposits are usually more massive, so that a number of geophysical or geologic methods may be used in locating this type of deposit.

MAGNETIC METHODS

A primary deposit of ilmenite accompanied by magnetite or hematite can be detected by aeromagnetic or ground-magnetic surveying, provided that the deposit is not too small or buried to too great a depth. For initial reconnaissance a dip-needle survey can be most helpful. Magnetite-ilmenite deposits give a positive anomaly, the size of which is proportional to the magnetite content of the deposit and may not have any relationship to the ilmenite content. Because these positive anomalies are caused by magnetite, they do not necessarily indicate areas of titaniferous mineralization; only field checking can determine if ilmenite is present. Assemblages of ilmenite and hematite are readily detected by the airborne magnetometer but give negative rather than positive anomalies. This phenomenon is especially noticeable for large deposits, such as that at Allard Lake, that may contain ilmenite having 15 to 20 percent of included hematite.

Bodies of pure ilmenite cannot be revealed by the magnetometer, although large deposits might be detected by electromagnetic devices such as the mine detector used by the armed services. Actually, however, most large ilmenite-bearing deposits contain either magnetite or hematite and can be detected by the magnetometer.

* By Robert Lawthers, formerly geologist, Federal Geological Survey.

GRAVITY METHODS

In general, nonmagnetic geophysical methods are not particularly applicable to prospecting for primary titaniferous deposits. A possible exception are gravity surveys, which might be used for detecting large ilmenite-bearing deposits in areas of low relief, although magnetometer surveys probably would give quicker and more accurate results.

GEOLOGIC METHODS

Geologic investigations help physical prospecting to varying degrees and are indispensable in evaluating deposits. Ilmenite-bearing bodies in anorthosite-gabbro complexes generally occur near the margins in either anorthosite or gabbro. Detailed geologic mapping of some deposits, such as Iron Mountain, Wyo., has shown that structural and petrological features control mineralization and can guide physical exploration for concealed deposits (Newhouse and Hagner (151)). In large gabbroic bodies, such as the Duluth gabbro, the ilmenite-magnetite bodies appear to be randomly distributed, and the value of detailed geologic investigation remains to be determined in predicting the location of "ore." In layered norite complexes, the stratigraphic position of the titaniferous layers and associated country rocks is rather consistent and can be determined by detailed geologic investigation. Because layers in some of these deposits may extend for miles, the position of the titaniferous layers, where concealed, may be readily determined if the geology is known.

The size and shape of known deposits in any given area must guide prospecting and development. Most ilmenite-bearing deposits in anorthosite are tabular or lenticular and have various attitudes; some of the large deposits, such as Allard Lake, Quebec, are very irregular masses. In gabbroic bodies the common occurrence of titaniferous bodies as small pods, discontinuous lenses, and irregular dike-like masses increases the difficulty of tracing deposits or predicting their extensions, either horizontally or vertically.

PROSPECTING FOR SECONDARY DEPOSITS

MAGNETIC METHODS

Secondary deposits are not as susceptible to geophysical detection as the primary ones.

Magnetometer surveys will detect only the titaniferous deposits that contain considerable magnetite and are not covered by thick overburden. Some of the richer, magnetite-bearing black-sand deposits cannot be detected because of their small size, whereas many larger deposits are too lean for detection.

RADIOACTIVITY METHODS

In some places titanium-bearing black sands contain radioactive monazite whose presence may be revealed by airborne radiation-detection equipment. On the beaches and raised inland terraces of Florida, Georgia, and the Carolinas, for example, many of the larger black-sand deposits contain enough monazite to permit detection by airborne radioactivity surveys. However, utilizing the radioactivity of monazite in black sands as an aid in prospecting for titaniferous minerals has several limitations; these are: (1) The proportions of monazite and titanium-bearing minerals in deposits may be expected to vary widely; (2) some rich titaniferous deposits contain so little monazite as to be unobservable in airborne radioactivity surveys; (3) some rich deposits may not be large enough for detection; and (4) the radioactivity in an area may be caused by primary deposits containing radioactive minerals other than monazite.

GEOLOGIC METHODS

In prospecting for titanium-bearing black-sand deposits along modern beaches, certain locations are much more favorable than others. The better deposits are apt to occur on the windward side of headlands or other promontories, where heavy-mineral layers are built up by the accumulation of sand swept along the beach by waves and currents. Individual heavy-sand layers vary considerably in thickness and lateral extent along the beach; some beds are short and thin, others may extend along the beach for hundreds of feet. The erratic distribution of heavy sands in this type of deposit necessitates detailed sampling to determine grade and tonnage and in many places makes mining uneconomical.

Prospecting for buried deposits of heavy-mineral sands in raised terraces, such as occur in Florida and Georgia, requires a combination of techniques. Over large areas there may be no surface indication of buried deposits, and overburden may be so thick that magnetic methods are ineffective. Under these circumstances systematic exploration requires extensive drilling and careful geologic study. Sub-surface correlations based on drill data can outline buried shoreline features that controlled the concentration of heavy sand. Regional studies can indicate the probable sources of the

sands and courses of transportation and so eliminate less favorable areas. For example, some scarps can be traced for miles along coastal terraces and may represent old shorelines. As a consequence, the areas around these scarps might be favorable places for investigation. Although there is no way to avoid excessive drilling, particularly in the early stages of such a program, careful geologic interpretation undoubtedly could save a good deal of wildcat drilling in the later stages.

Where stream placer deposits cannot be located by geophysical methods, geologic studies may help to reveal old or buried narrow valleys, gorges, or steep gradients below which the best deposits generally occur. A real reconnaissance will also locate favorable sites, such as large flats. Because the black-sand layers may be irregular in shape and erratic in distribution and because irregularities in the rock floor of the deposits may contain concentrations of heavy minerals, most placer deposits can be evaluated only by drilling.

The discovery of residual titanium-rich deposits can be helped by detailed geologic mapping. Such work outlines the areas favorable for lateritic soil and provides information on the composition of the underlying bedrock and on the nature and relief of the contact between bedrock and soil. The best titanium-bearing residual deposits overlie basalt and ferromagnesian rocks that contain a relatively high proportion of ilmenite relative to other minor minerals. For example, in the northwestern United States basalt that has appreciable amounts of accessory magnetite and ilmenite is overlain by lateritic deposits containing as much as 7.3 percent TiO_2 as altered ilmenite. In general, geophysical methods are of little help in prospecting residual deposits. Seismic methods might be used to obtain the thickness of deposits, although the gradational character and irregular profile of the contact with the underlying bedrock would make results uncertain and difficult to interpret. Electrical methods utilizing the resistivity of deposits might assist in determining their thickness, although these methods would probably be subject to considerable error and would have to be checked by drilling or trenching.

MINING AND BENEFICIATION

Of the total ilmenite production in 1954, New York supplied over one-half and Florida about one-third; the remainder came from Virginia and Idaho. Since the 2 major sources represent 2 different types of ore and hence different methods of mining and beneficiation, each is discussed in some detail. The smelting of ilmenite to produce a titanium slag is an

important new development that also merits discussion.

NEW YORK—THE MACINTYRE DEVELOPMENT

Before 1941 interest in the ore body at Lake Sanford, Essex County, N. Y., was small and was confined to the iron content of the ore. In 1941 the National Lead Co. took over the property and constructed a plant, the main purpose of which was to recover the ilmenite values. The mill went into production in 1942. From 1942 until 1953, 12.4 million tons of ilmenite-magnetite ore was removed from the ore body. Products during this time totaled 2.3 million tons of ilmenite and 4.8 million tons of magnetite concentrates.

THE ORE BODY

In the Lake Sanford area there are 4 ore bodies, but only 1—the MacIntyre deposit—is mined at present. This deposit contains ore analyzing 18–20 percent TiO_2 and 34 percent iron. The ore is present in coarse-grained ilmenite and magnetite veins, lenses, and pods in anorthosite and gabbro. Mineralogically, the ore averages 32 percent ilmenite, 37 percent magnetite, 16 percent feldspar, and 15 percent iron silicates.

MINING

The ore body occurs as an outcrop on the side of Sanford Hill and lends itself to open-pit bench mining. The deposit is approximately 1,800 feet long and 900 feet wide, and the lenses dip between 45° and 80° toward the west.

To maintain the mining operations approximately 1.25 tons of waste must be removed to recover 1.0 ton of ore. The optimum height of the mine benches is 35 feet.

Drilling in preparation for blasting requires use of a 9-inch bit, with which a hole averaging 39 feet in depth is drilled at the rate of approximately 5.24 feet per hour. Each hole is then charged with 340–500 pounds of dynamite. Primacord is used to detonate the dynamite, and millisecond-delay caps are used to reduce backbreak and give better fragmentation. The properties of the ore are such that some large pieces are produced after primary blasting. Secondary breakage is accomplished by mud-cap blasting or more usually by means of a dropball crane.

Electric shovels load the ore aboard 22-ton diesel-powered trucks for haulage to the beneficiation plant.

BENEFICIATION

Primary crushing to an 8-inch product is made in a 48- by 60-inch jaw crusher; secondary

crushing to $1\frac{1}{2}$ inch is carried out in a 7-foot cone crusher, and final stage crushing to $\frac{3}{8}$ inch is done by means of two $5\frac{1}{2}$ -foot cone crushers. Intermediate screening and magnetic separation steps eliminate some of the waste material. Figure 10 shows the flow of material through the wet mill.

After reduction to minus- $\frac{3}{8}$ -inch the partly beneficiated material is fed to 6- by 12-foot rod mills, grinding in closed circuit with 28-mesh vibrating screens. The minus-28-mesh material is separated into 2 products by low-intensity magnetic separation. In this step the magnetite reports in the magnetic fraction containing about 9 to 10 percent TiO_2 and 58 percent Fe, which is dewatered and sent to storage to be followed by sintering to make a material suitable for blast-furnace feed. The nonmagnetic fraction from the separators, containing the ilmenite, is sent to hydrosizers in which the material is graded into eight sizes from 20-mesh to minus-150-mesh. Further beneficiation by means of reciprocating tables results in a product containing 37–38 percent TiO_2 .

The table concentrates are dewatered by filtration and then dried completely by steam-coil driers. Dry magnetic separators are used to upgrade the ilmenite to a final product containing, on the average, 45 percent TiO_2 .

Each of the above wet steps—the wet magnetic separation, the magnetite dewatering, and the hydrosizing—results in a large amount of slimes. The ilmenite values in these slimes are recovered in a flotation plant. Equipment used in this operation includes thickeners 22 feet in diameter, dewatering rake classifiers, cyclone-type separators, and flotation cells. The flotation concentrate that contains the ilmenite is filtered, then stored or shipped.

FLORIDA BEACH SANDS

The titaniferous reserves in the Florida beach and dune sands are large and have been mined intermittently since 1916. In 1954 dredging and beneficiating equipment was being operated in this area by four concerns: E. I. du Pont de Nemours & Co., Inc., at Starke; the National Lead Co., Titanium Division, and the Rutile Mining Co. at Jacksonville; and the Florida Ore-Processing Co. at Melbourne.

The sands processed in these operations contain a heavy fraction that represents approximately 1 to 4 percent of the ore. Mineral constituents of this heavy fraction vary considerably from deposit to deposit. The heavy fraction of one large producer contains about 40 percent ilmenite, 4 percent leucoxene, 7 percent rutile, 11 percent zircon, and less than 0.5 percent monazite.

WET MILL

One mill section of four with regrind circuit and flotation

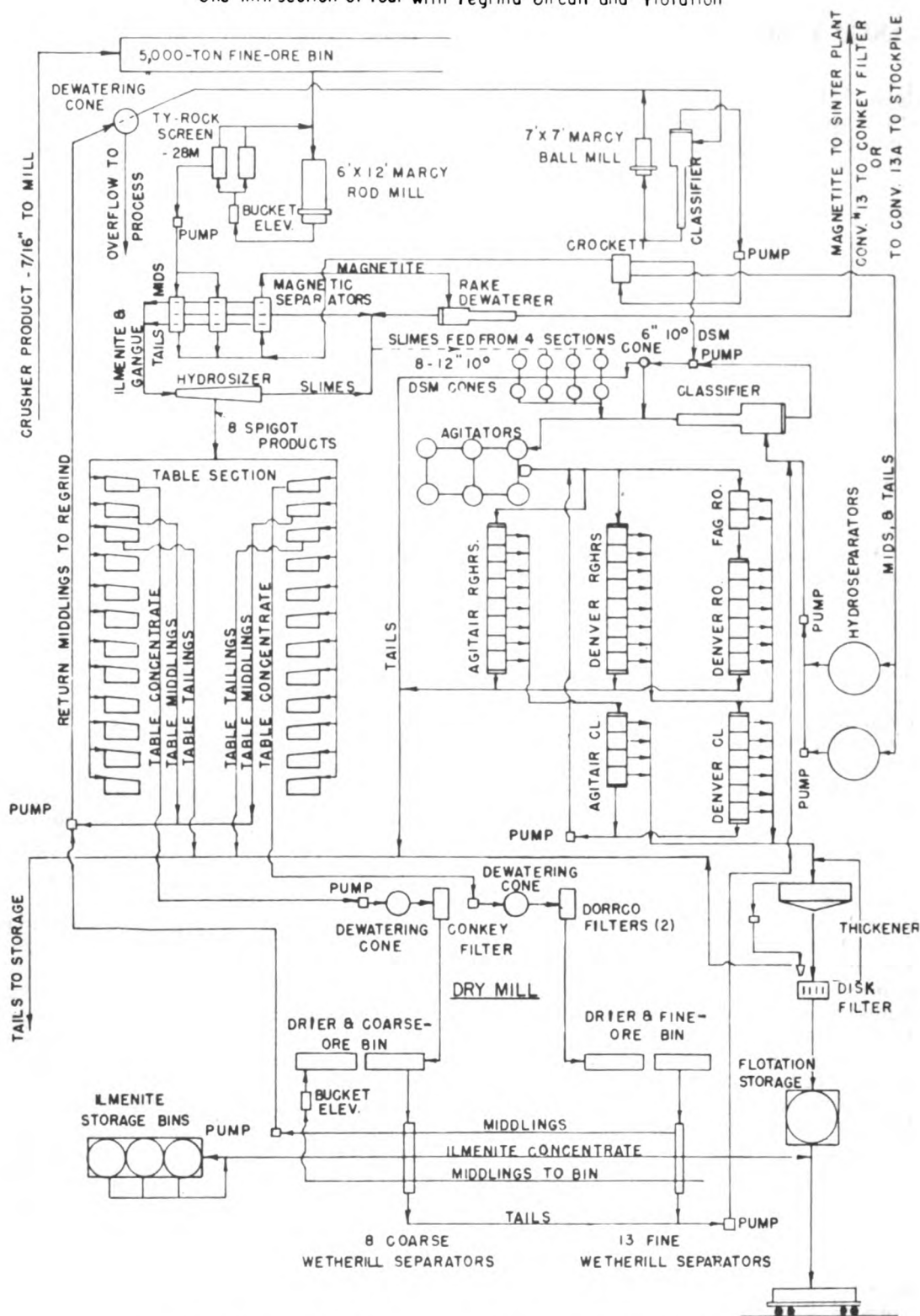


Figure 10.—Flowsheet for Tahawas, N. Y., Plant of National Lead Co.
(Courtesy, National Lead Co.)

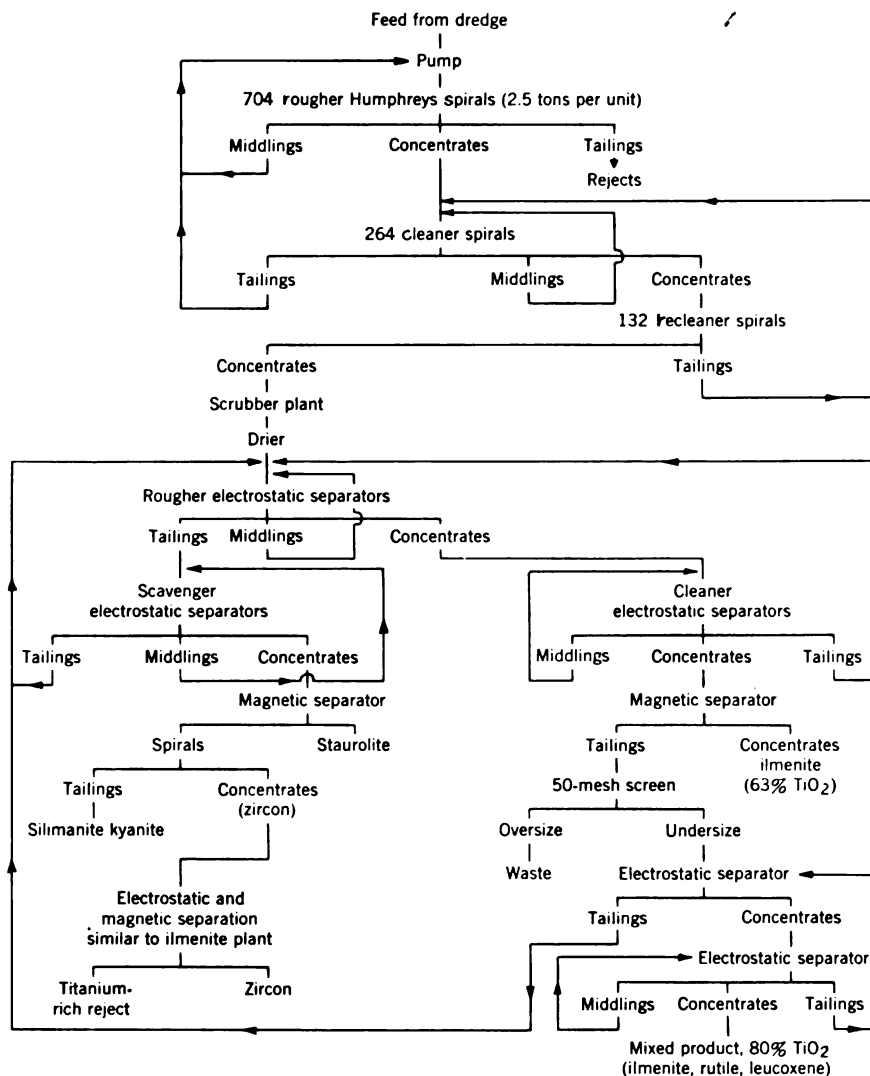


FIGURE 11.—Flowsheet for Trail Ridge, Fla., Plant of E. I. du Pont de Nemours & Co., Inc.

MINING

Considerable information is available on the Du Pont operation at Starke, and it is typical of these operations. The Humphreys Gold Corp. mines the Starke deposit for Du Pont; it is essentially a dredging operation (figure 11 shows a flowsheet). Before actual dredging it is necessary to prepare the surface ahead of the dredge by removing the hardpan. Preliminary preparation includes removal of the standing timber, stumps, and roots. Eight-inch-diameter holes are then drilled approximately 20 feet apart and parallel to the face of the dredge pond. The holes are loaded and detonated, and the resulting blast loosens the hardpan so that it is in a form amenable to dredging.

A suction cutterhead dredge 20 inches in diameter, capable of digging 1,200 tons an hour

to a depth of 45 feet below the water surface, is used. The slurry, consisting of 10 to 15 percent solids, is pumped at the rate of 20 tons of solids per minute to the beneficiating barges.

BENEFICIATION

The pulp is screened on a $\frac{1}{4}$ -inch screen to remove the oversize and trash. It is then dewatered to a slurry containing about 30 percent solids. This slurry is distributed to a battery of Humphreys spiral classifiers, where the first rougher concentration is made. In this step over 700 spirals, all mounted on a single barge, are used. Spirals are also employed in the cleaner and recleaner steps, 264 being required in the first and 132 in the second.

The concentrates from the recleaner are pumped ashore as 25 percent solids and at a

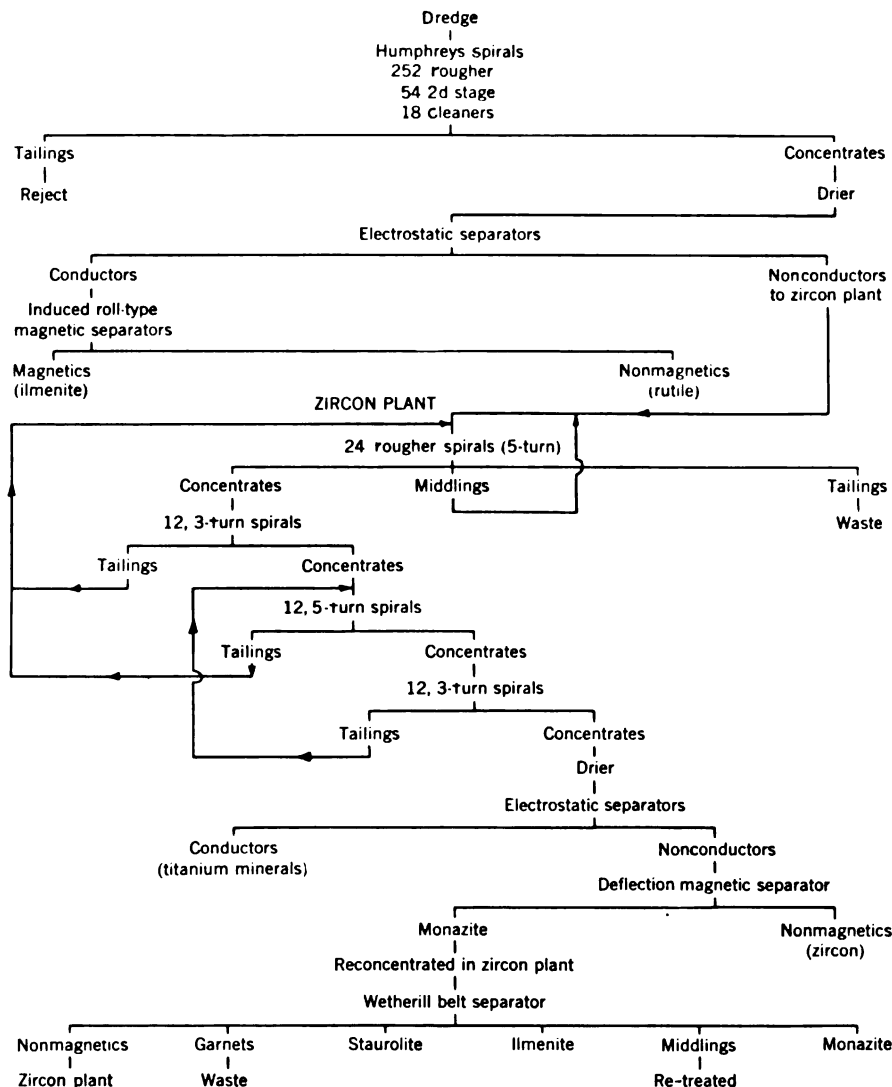


FIGURE 12.—Flowsheet for Jacksonville, Fla., Plant of Titanium Alloy Manufacturing Division, National Lead Co.

rate of 30 to 45 tons per hour. This material is dewatered, scrubbed to remove some of the organic coating, and then stockpiled until it is required in the dry-mill operations. In the dry mill the concentrates are dried and heated to about 220° F. and then distributed to rougher high-tension electric separators. Further cleaning and concentration on electrostatic separators are followed by magnetic separation to recover the ilmenite, which reports in the magnetic fraction. The nonmagnetic material is screened to remove staurolite as a coarse fraction, and the fines are cleaned electrostatically to recover leucoxene.

The above steps may be summarized as follows:

1. Feed from dredge: 15 percent solids, 1.3 percent TiO_2 .

2. Discharge from rake classifier: 65 percent solids.

3. First-stage spirals: Feed, 1.4 percent TiO_2 , 30 to 35 percent solids; middling, 1.8 percent TiO_2 ; concentrate, 4 percent TiO_2 ; tailing, 0.3 percent TiO_2 .

4. Second-stage spirals: Feed, concentrate from first-stage; middling, 5 percent TiO_2 ; concentrate, 15 percent TiO_2 ; tailing, 1.5 percent TiO_2 .

5. Third-stage spiral: Feed, concentrate from second stage; final product (to dry mill), 27 percent TiO_2 .

6. Dry electrostatic separation to discard silicates.

7. Dry magnetic separation of ilmenite containing 63 to 66 percent TiO_2 and a nonmagnetic fraction containing 80 percent TiO_2 (leucoxene).

In this operation 2 percent of the feed to the plant is titaniferous material, and of this approximately 70 percent is recovered in the final product.

The plant at Jacksonville, Fla., operated by Humphreys Gold Corp. for the National Lead Co. differs from the Du Pont operation in that

the spirals are not mounted on dredges and the sand feed to the plant is much less abrasive. The flowsheet in figure 12 summarizes this operation. The cast-iron sections of the spirals show little erosion, while in the Du Pont plant the equipment must be Neoprene- or rubber-covered to decrease wear. Byproducts from the National Lead Co. operation include both zircon and monazite containing 4.5 percent ThO_2 and 56 percent total rare earths.

ALLARD LAKE—TITANIUM SLAG

GENERAL

At Lac Tio in the Allard Lake region, Canada, the Quebec Iron & Titanium Corp. is mining the largest known ilmenite deposit in the world. The ilmenite is intimately associated with hematite, so that ordinary beneficiation practices cannot be used. The operation is important because the titanium slag produced from the ilmenite is becoming an important raw material in producing titanium pigments and may become the source material for titanium metal as the metal industry expands. It may also be used as a substitute in almost all of the other applications of ilmenite and rutile.

The Quebec Iron & Titanium Corp. is two-thirds owned by Kennecott Copper Corp. and one-third by the New Jersey Zinc Co. It ships the Lac Tio ore 550 miles up the St. Lawrence River to its facilities at Sorel, where the ilmenite is smelted into pig iron and titanium slag. A large amount of money was required to get the mine and smelter into the production stage. A 27-mile railroad had to be constructed through a mountain and over a swamp between Lac Tio and Havre St. Pierre, dock facilities built at Havre St. Pierre and at Sorel, houses erected for the workers, smelters assembled at Sorel, and the mining area at Allard Lake readied for operation. The cost of getting the project started, as of January 1, 1952, follows:

Exploration.....	\$500,000
Mine development.....	2,200,000
Mine property.....	400,000
Mine construction.....	1,700,000
Havre St. Pierre terminal.....	3,200,000
Railway.....	7,700,000
Smelter.....	16,400,000
Experimental operation of smelter.....	2,200,000
Total.....	34,300,000

At this point mine production was scheduled at 3,000 tons per day, although construction had not yet been completed on 4 of the 5 furnaces. By 1955 Kennecott Copper Corp. and New Jersey Zinc Co. had invested over \$50 million in the venture.

In 1954, 1 of the 5 smelting furnaces was run on an experimental basis, and discoveries were made that resulted in modification of the fur-

nace design and changes in operating methods that should lower costs.

The production history of this company, expressed in short tons, was as follows:

	1951	1952	1953	1954
Ore mined and crushed.....	379,931	265,719	158,218	308,974
Ore treated.....	49,615	104,166	332,863	282,752
Titanium slag produced.....	19,330	42,141	141,833	122,960
Titanium slag shipped.....	8,041	38,908	145,402	119,292
Iron and steel produced.....	14,422	32,422	106,875	90,562
Iron and steel shipped.....	5,701	33,630	94,587	100,509

MINING

The ore body at Lac Tio is composed of massive ilmenite in sharp contact with the anorthosite country rock. It is mined by standard open-pit methods, utilizing wagon drills, power shovels, and trucks. Each of the benches in the pit is 25 feet wide and 25 feet high. Overburden (which is only 2 or 3 feet thick) is removed by bulldozers.

Pit operators check the ore closely to keep gangue shipped to a minimum. Ordinarily, shipments run 88–90 percent ore, with a 90-percent ore containing about 35 percent TiO_2 and 40 percent Fe. The ore that has been blasted loose is loaded aboard trucks by power shovel and hauled to the ore bins. At the bins the ore is crushed in a jaw crusher that can handle masses of rock up to 4 feet in diameter.

After crushing, the ore is put on railroad cars to be hauled 27 miles on the railroad built by the company to Havre St. Pierre. From thence it is transported by ship to the smelters at Sorel.

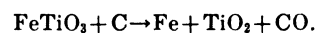
BENEFICIATION BY SMELTING

The ore is shipped to Sorel because a large supply of electricity, provided by Shawinigan Water & Power Co., is available there for the electric smelting furnaces.

The ore is mixed with coal, dried, and then crushed. Three hundred tons of ore mixed with 43 tons of coal is required for each furnace per day. This amount of ore yields 132 tons of titanium slag and 96 tons of iron.

The furnaces are box-shaped, steel-framed, and refractory-lined, containing 6 graphite electrodes in line or 2 for each phase of the 3-phase, 224–390 volts. The power is supplied through Amplidyne controls, which automatically regulate elevation of the electrodes to maintain the proper temperature and arc voltage. Smelting temperature is 3,000° F.

The feed of the ore to the furnace is continuous, care being taken to keep the hot slag away from the refractory lining. Tapping of the slag and iron is intermittent. Coal acts as the reducing agent in the reaction, which may be expressed by the following equation:



The furnace atmosphere is thus maintained at a positive pressure, containing about 80 percent CO. Surplus CO is scrubbed and used in the heating plant and ore driers.

The slag is tapped off periodically into 35-ton cast-steel pots. The pot dumps the slag into a modified pig-casting machine where it is water-quenched and dropped onto a surge pile. This rapid cooling causes the slag to have a small grain size and results in formation of a fairly large amount of TiO_2 that is insoluble in H_2SO_4 . To eliminate this shortcoming, the plant began switching over to block casting of slag in early 1955. In this operation the slag is poured into large molds carried on small flat cars. The filled molds are pulled into a quenching chamber, where water sprays are used to cool the molds slowly, resulting in the slag having a larger grain size and in the formation of a smaller amount of insoluble TiO_2 . After crushing, the slag is stored in a covered storage bin until it is shipped.

The molten iron is tapped into a 60-ton ladle every 12 hours and transferred to a 60-ton arc-type refining furnace. Because the iron contains considerable sulfur, lime and fluxes are introduced into the molten bath by nitrogen-gas flow through an expendable steel lance. The refined iron is then cast into pigs by a casting machine.

As a result of experimental work in 1954 at Sorel many of the practices outlined have been undergoing change. Upgrading and pretreatment of the ore have resulted in increased furnace capacity. Methods of charging the furnace and controlling its operation have been changed, further increasing furnace capacity and lengthening the life of the refractories. Iron from the treatment furnace is now desulfurized in the ladle rather than by the more costly method of electric-furnace refining. By-product fuel gases are being used as a source of heat in pretreating the ore.

CHAPTER 5. PROCESSING

PRODUCTION OF METAL

Although the element titanium was discovered in 1790 by William Gregor, it was not until 1910 that M. A. Hunter succeeded in producing virtually pure titanium by reducing titanium tetrachloride with sodium in a steel bomb. Nilson and Peterson pioneered Hunter's experiments in 1887, but their reduction of titanium tetrachloride with sodium resulted in a product contaminated by oxygen. Henri Moissan also produced an impure metal by reducing TiO_2 with carbon in an electric furnace in 1895.

In 1922 Van Arkel and de Boer dissociated zirconium iodide on a hot surface into a high-purity metal and later applied this same process to titanium to produce a ductile metal. Dr. Wilhelm Kroll became interested in titanium in 1928, producing the metal by the Hunter bomb process. By 1938 he had invented the process for producing titanium by reducing titanium tetrachloride with magnesium under an inert atmosphere. The Bureau of Mines had been investigating various methods of producing titanium since 1938, and in 1942 it concentrated on development of the Kroll process. In the following years the Bureau of Mines stimulated interest in the metal by operating a pilot plant and distributing free samples to various organizations. The first commercial production was by E. I. du Pont de Nemours & Co. in 1948, followed in succeeding years by other companies.

In the past few years interest has centered on producing pure metal by electrolytic methods, and several companies now operate electrolytic pilot plants; however, no company has as yet advanced this method to the point where it has commercial value. The Bureau of Mines is conducting experiments on the electrolytic refining of titanium, by which low-quality sponge or scrap may be refined into a ductile metal.

Since 1948, when the annual production of titanium metal was 10 tons, the industry has expanded rapidly, having produced 5,370 short tons in commercial operations in 1954. All of this metal was produced by the magnesium reduction of titanium tetrachloride. In addition, a minor amount of metal was manufactured by the iodide process. The planned annual capacity of the titanium industry in June 1955 was 22,500 short tons.

One company in the United States and one company in England were building plants in 1955 to employ the sodium reduction of titanium tetrachloride. Details of the techniques to be used were not divulged. If sodium is used it is possible to introduce the sodium into the reactor as a liquid during the reduction as opposed to the Kroll process, wherein the magnesium is sealed in the reactor before reduction.

IODIDE PROCESS

The production of titanium by the iodide process in 1954 was relatively small, resulting in a high-purity metal generally containing a few thousandths of 1 percent of oxygen and nitrogen. This metal was produced primarily for research purposes, but attempts were being made to expand this method to produce metal on a much larger scale. During 1954 the Foote Mineral Co. produced only 250 pounds of titanium by the iodide method. In 1954 commercially pure sponge was selling for \$4.50 per pound, and the high-purity material was priced at \$125 per pound in less than 100-pound lots.

The process is based upon the reaction of crude titanium metal with iodine to form the volatile tetraiodide, which is then decomposed on a hot wire at temperatures between 2,000° and 2,730° F. Iodine liberated at the hot filament is then available to again react with crude titanium in the cooler portions of the reactor.

A metal tube 30 inches in length and 4¼ inches in diameter has been used in some production runs. Twelve to fifteen pounds of crude titanium was charged to a ½-inch annular space between the walls of the cylinder and a perforated-sheet molybdenum screen. Iodine was contained in a side tube, which was refrigerated until the main unit had been evacuated. The filament used was a 24-inch-long loop or hair-pin of either titanium or tungsten wire. The entire assembly was installed in an oil bath held at 330° F.

As the thickness of the deposit on the filament increased, the current also had to be increased to maintain a filament temperature exceeding 2,000° F. At higher current densities dissipation of heat became a major problem, therefore the thickness of the deposit was limited by the efficiency of the apparatus in dissipating heat. By using a metal-tube apparatus immersed in an oil bath, the current

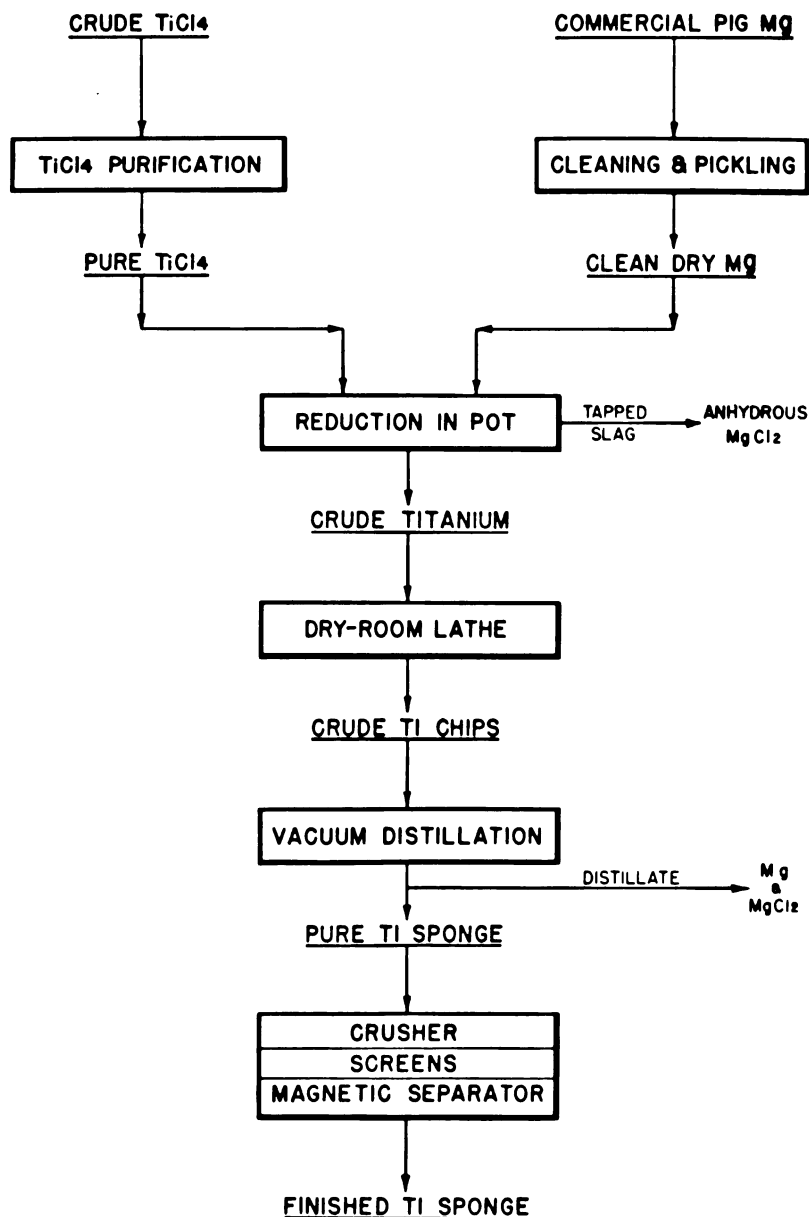


FIGURE 13.—Flowsheet for Producing Titanium Sponge.

could be increased to a maximum of 580 amperes, which yielded a rod up to $\frac{5}{8}$ inch in diameter, weighing over 700 grams. If a Pyrex tube was used, the current could only be increased to 300 amperes, producing a rod $\frac{1}{4}$ inch in diameter. About 30–48 hours per run has been required when a metal tube was used.

The deposits on the wire were coarsely crystalline, with the coarseness decreasing as the temperature of the wire was increased.

MAGNESIUM-REDUCTION PROCESS

The magnesium-reduction process was developed on a laboratory scale by Wilhelm J.

Kroll and was expanded to a pilot-plant operation by the Bureau of Mines. As developed in the Bureau of Mines laboratories purified titanium tetrachloride is reduced to the metallic state with magnesium in an inert atmosphere of helium or argon. (See fig. 13 for flowsheet.) Most of the magnesium chloride formed during the reaction is drained to remove it from the titanium metal and to prevent slowing of the reaction rate. The remaining magnesium chloride and excess magnesium are removed from the spongelike titanium by leaching or vacuum distillation. The sponge is then consolidated by one of a variety of methods.

Actual procedures for producing sponge commercially are closely held company secrets; however, techniques essentially follow those developed by the Bureau of Mines. One company is planning to use sodium rather than magnesium as a reducing agent when it begins operations in 1956.

PREPARATION OF TITANIUM TETRACHLORIDE

As indicated in chapter 1, metallic titanium is extremely sensitive to the presence of very small amounts of impurities. Since all metallic and some of the nonmetallic impurities present in TiCl_4 appear in the sponge produced, high-purity titanium tetrachloride must be used. The major part of the production of tetrachloride in 1954 was based upon the reaction of rutile with chlorine in the presence of carbon. An exception to this was E. I. du Pont de Nemours & Co., which chlorinated a mixed product of ilmenite, rutile, and leucoxene that it describes as ilmenite.

There are many difficulties in chlorinating ilmenite. A large amount of chlorine is consumed to chlorinate the iron, and the byproduct FeCl_3 formed has no market value. Also larger chlorinating units must be employed to produce the same amount of TiCl_4 from ilmenite as could be produced from a smaller unit chlorinating rutile; that is, the output of a standard unit would be reduced if it were to switch from rutile to ilmenite as a feed material. Aside from these economic considerations, the use of ilmenite in chlorinators presents a number of technical problems. The condensing system is continually plugged with ferrous and ferric chlorides if ilmenite is used; and when FeCl_3 and TiCl_4 condense together, a heavy mud is produced that is difficult to handle in a continuous process.

Much experimental work has been carried out on chlorination of titanium slag. The main difficulty has been that the magnesium and calcium in the slag produced in 1954 formed a pasty mass, which clogged the reaction bed. Other chlorine consumers in the slag increased chlorine consumption over that needed for rutile with a concurrent cutback in unit output of TiCl_4 . Higher grade slags probably will be produced to minimize the chlorination problems.

There are two main types of chlorinators for producing titanium tetrachloride: The static-bed or shaft chlorinator and the fluidized-bed chlorinator. Preparation of the rutile for chlorination depends upon the type of chlorinator used. The static-bed chlorinator requires that the rutile be briquetted or sintered before it can serve as feed material, while the fluidized-bed chlorinator employs ground coke and rutile fed directly to the bed.

In preparing the briquets for the static-bed chlorinator the rutile must be well mixed with carbon. One process consists of baking a mixture of coal or coke, coal tar, and rutile. Measured amounts of these ingredients are fed into a steam-heated pug mill, where they are properly mixed. The mix is then fired in a circular tunnel kiln, in which the volatile material is burned off and the tar coked. The finished sinter is broken up into lumps and transferred to storage.

The static-bed chlorination furnace is electrically heated by power supplied to carbon resistor blocks to start the reaction. After the process has been initiated, it is no longer necessary to supply heat, as the reaction is exothermic. The briquets are fed to the top of the furnace and form a bed on the carbon blocks in the bottom. Preheated gaseous chlorine is passed up through the bed of briquets, reacting to form titanium tetrachloride, carbon monoxide, and carbon dioxide. The gaseous tetrachloride is cooled and condensed by spraying it with previously liquefied product. Settling and/or filtration is then used to remove any insoluble material and sludge.

One disadvantage of the static-bed chlorinator is that nonreactive material accumulates in the bed, and the apparatus must therefore be shut down periodically for cleaning. The fluidized-bed chlorinator eliminates this disadvantage, as the nonreactive material is continually removed by overflow. Also the briquetting or sintering step is not necessary in preparing the material for the fluidized-bed chlorinator, as the ground rutile and coke are fed directly to the bed. The unit is preheated by burning coke, and the desired heat rate is maintained during the starting period by passing in dried flue gas and air in the proper proportions.

Final purification of the liquid titanium tetrachloride requires both chemical treatment and fractional distillation. The Bureau of Mines, in its operations at Boulder City, Nev., selected the hydrogen sulfide method of purifying titanium tetrachloride because it was positive and easily applied.

Treatment with H_2S at 90°C . removed virtually all the vanadium and iron present, forming a brown-to-black precipitate. Many other metal chlorides were decomposed into sulfides by H_2S , and still others were reduced to lower chlorides, usually having a much higher boiling point than TiCl_4 and therefore easily separated.

After sulfiding, the entire charge was sent to the fractionating still, where the TiCl_4 was brought to boiling and the vapors were passed through a reflux column. The reflux column separated volatile gases and other low-boiling

constituents from the TiCl_4 during fractional distillation. Many of these impurities were vented out of the system at this point, and portions were condensed with a small amount of titanium tetrachloride, which was recycled into the next batch. After fractionation for the proper length of time, the resulting slurry of TiCl_4 and solid impurities was sent to a pot still where the pure TiCl_4 was volatilized away from the solid impurities. The pure TiCl_4 vapors passed to a condenser and thence to storage, from which it could be drawn to the reduction cycle.

PRODUCTION OF CRUDE SPONGE

Using the magnesium-reduction process, the Bureau of Mines produced 200-pound batches of metal. Although industry in 1954 also used essentially the same method as the Bureau of Mines, some of the companies in commercial operation turned out 2,000-pound batches. Because of the paucity of information on techniques used by various companies, only the Bureau of Mines operations at Boulder City, Nev., will be described.

Figure 14 illustrates the reduction pot and furnace used by the Bureau of Mines. The reduction pot was made up of two parts—the lower container or pot proper and the lid that carried a top column. The top column provided for the following: Inlet for TiCl_4 ; gas bleedoff outlet to adjust internal pressures; helium inlet to adjust internal pressures; inlet line for manometer connection; and thermocouple tube through which the internal temperature could be obtained. Additional features of the pot were: A taphole at the bottom to permit drainage of magnesium chloride; thermocouple wells on the sides for temperature control; lugs and hooks to handle the pot and to attach it to the lathe to remove chips; an arrangement of flanges to permit welding the lid to the pot; and a means for air-cooling the column.

The furnace was of simple construction, as its chief purpose was to supply enough heat to melt some of the magnesium inside the pot. Heat was furnished by two gas burners. A third portable burner was used to heat the tapping spout before tapping magnesium chloride.

The reactor pot was loaded in the dry room with approximately 330 pounds of cleaned magnesium ingots, and the pot lid was lightly welded to the pot. (See figs. 15 and 16.) After being sealed and tested for leaks, the pot was moved to the evacuation station, which was located beside the furnaces. The vacuum line was connected, all valves were closed, and the pot was evacuated to approximately 27 inches of mercury. The vacuum valve was closed;

and, if the vacuum had not dropped by the end of 20 minutes, the pot was filled with helium, using one-half pound pressure. The pot was reevacuated and repurged with helium twice to assure elimination of as much air as possible before reduction.

When a furnace was ready, the pot was lowered into it with a crane. (See fig. 17.) The furnace lid was closed, and connections were then made with the TiCl_4 feed line, helium line, vent line, dry-air cooling line, and various thermocouples. The furnace burners were started, and the temperature controller was set at $1,380^\circ\text{F}$. After about $1\frac{1}{2}$ hours some of the magnesium had begun to melt, and TiCl_4 was introduced into the pot. The burners were turned off when the reaction generated enough heat to maintain the desired temperature of $1,380^\circ$ to $1,470^\circ\text{F}$.

About 2 hours after the feed had been started approximately 40 percent of the total feed was in the reactor, at which time molten magnesium chloride was tapped from the bottom of the pot. Tapping again took place after 60 percent of the total feed had been added and also after all of the feed had been added.

After complete addition of the titanic chloride, the burners were again turned on, and the temperature of the reduction pot at the controller point was held at $1,430^\circ$ to $1,530^\circ\text{F}$ for 1 hour. This final heating period allowed further drainage of magnesium chloride and probably tended to make some of the remaining entrapped magnesium available for reaction with any unreacted tetrachloride or lower chlorides. A final tapping was then made to remove as much magnesium chloride as possible from the pot.

The furnace was then cooled, the pot removed, and the weld ground off (fig. 18). Before the cover was removed (fig. 19), the pot was moved to a dry room. Here the cover was removed, and the pot was mounted in a lathe for removal of the product. In the boring operation care was taken to keep moisture pickup by residual magnesium chloride to a minimum, and the operation was at such a rate that danger of oxidation due to overheating was eliminated.

PURIFICATION OF CRUDE SPONGE

In 1954 final purification of the sponge by the Bureau of Mines, to remove residual magnesium and magnesium chloride, was by vacuum distillation. (Fig. 20 shows a vacuum-distillation furnace.) In this operation the chips resulting from boring out the reactor were placed in a basket and sealed inside a retort in a partly evacuated, electrically heated furnace. (See fig. 21.) The retort was evacuated to about 200 microns, and the bottom portion containing the basket was heated to

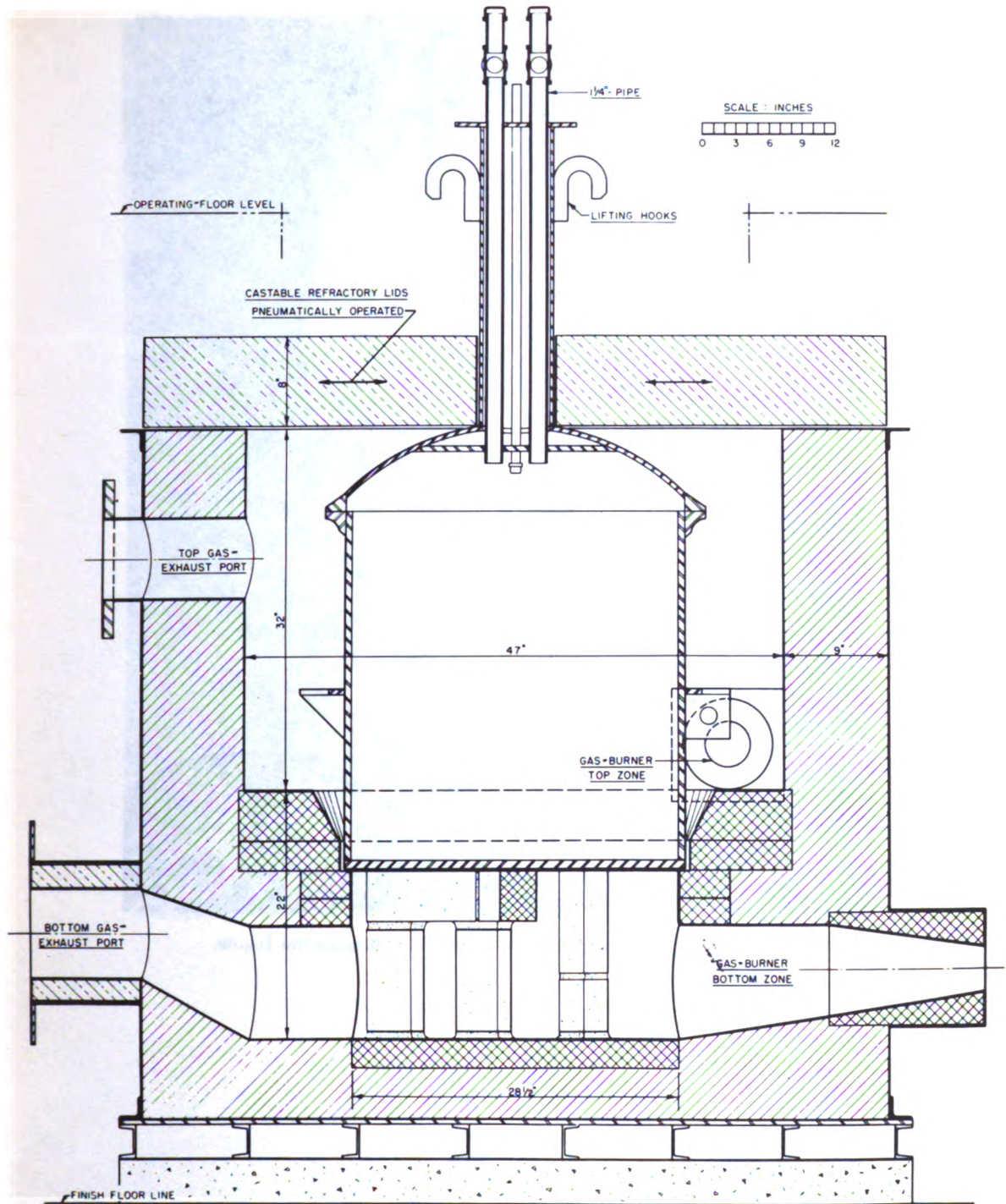


FIGURE 14.—Cross Section of Reduction Pot and Furnace Used by Bureau of Mines.



FIGURE 15.—Loading Reduction Pot With Magnesium Ingots.



FIGURE 16.—Welding Lid Onto Reduction Pot.

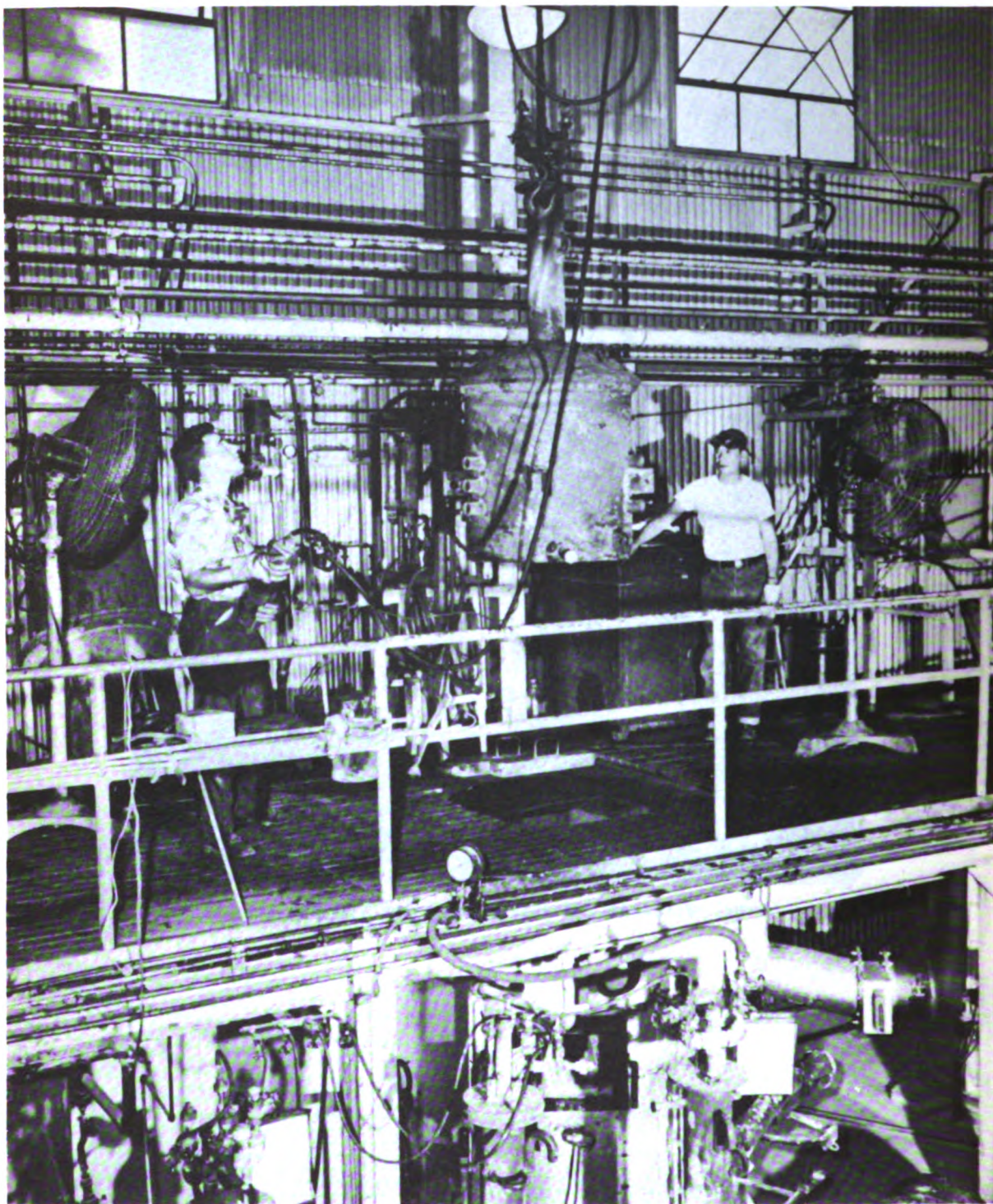


FIGURE 17.—Lowering Reduction Pot Into Furnace.

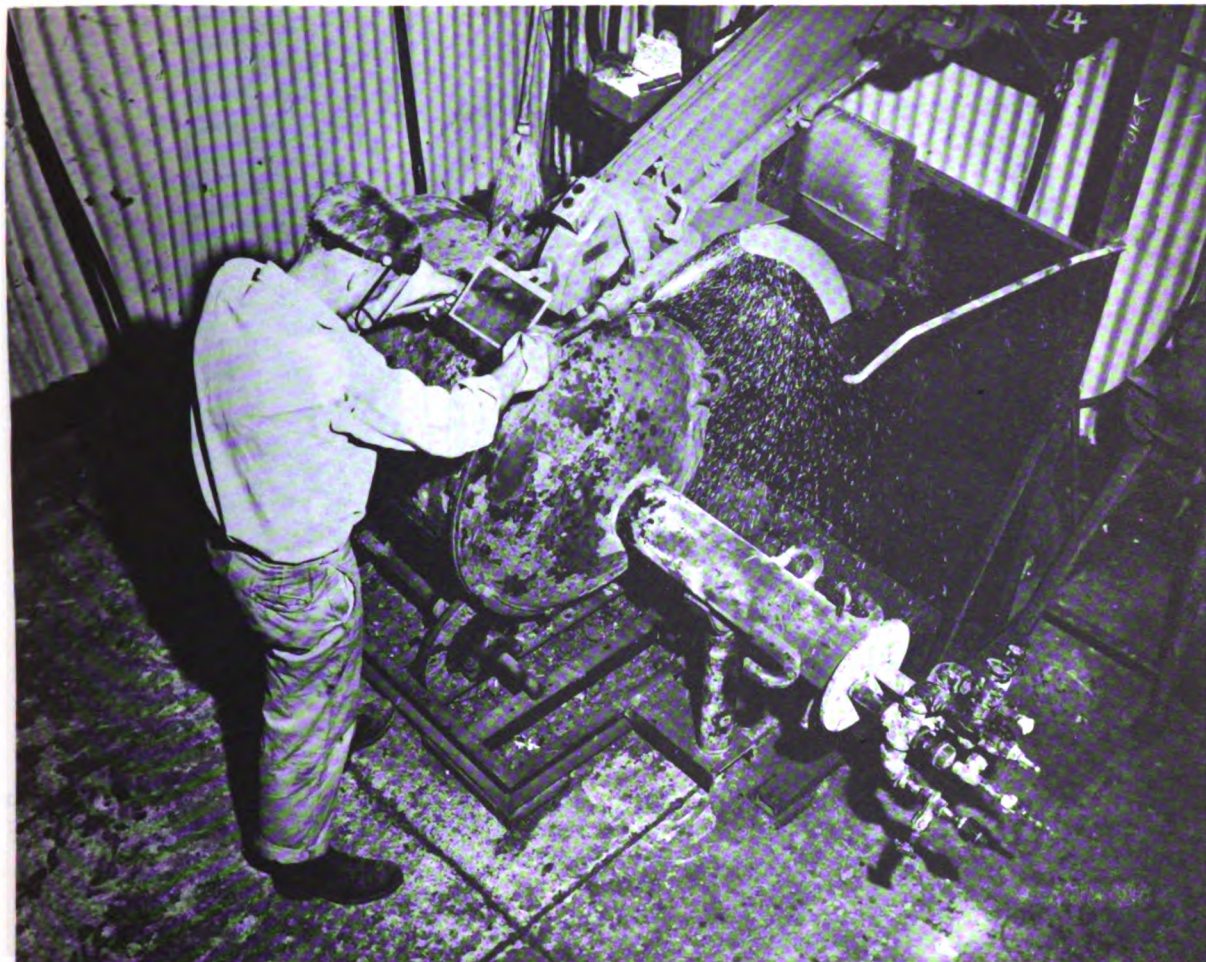


FIGURE 18.—Grinding Away Weld to Open Pot Filled With Reaction Mass.

and kept at a temperature of about $1,720^{\circ}\text{F}$. for 30–35 hours. The magnesium and magnesium chloride were volatilized and condensed in the upper part of the retort, leaving virtually magnesium-free titanium metal in a sponge-metal form in the chip basket. The vacuum not only protected the titanium from reaction with nitrogen and oxygen of air, but also permitted distillation of magnesium and magnesium chloride at much lower temperatures than their boiling points at atmospheric pressure.

Water-cooled surfaces and a series of baffles prevented the vapors from contaminating the vacuum pump. After the desired time at temperature, the power was cut off and the furnace allowed to cool below $1,580^{\circ}\text{F}$. Helium was bled into the retort until it contained a positive pressure of 1.5 pounds of helium, and dry air was bled into the furnace until it was at atmospheric pressure. The retort was removed from the furnace to allow more rapid cooling to room temperature. After cooling for about

22 hours, the helium in the retort was replaced by dry air to oxidize slowly the finely divided magnesium in the condenser.

During distillation the separate pieces of sponge sintered together so much that it was necessary to use a light pneumatic drill to chip the sponge from the sponge skeleton frame. (See fig. 22.) The sponge product removed was irregularly sized, ranging from a powder to 2- or 3-inch lumps. All lumps were reduced by a jaw crusher to minus- $\frac{1}{2}$ -inch.

Averaging results from a number of tests showed that the feed to the retort contained approximately 40 percent combined magnesium and magnesium chloride. The magnesium content of the sponge after distillation was 0.035 percent, and the chlorine content was 0.073 percent.

In earlier Bureau of Mines experiments dilute hydrochloric acid was used to dissolve the impurities from the metal chips. In this operation the ground, impure sponge chips were agitated at 66°F . in a hydrochloric acid solution

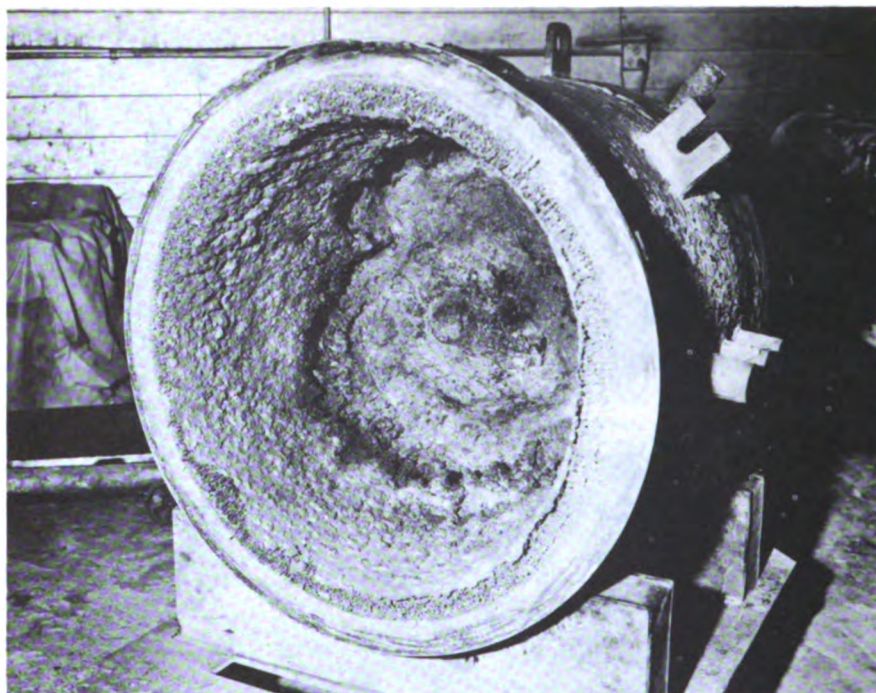


FIGURE 19.—Reduction Pot With Lid Removed, Showing Reaction Mass.

of pH 2 or less. The liquor was decanted, and the solids were ground in a steel ball mill, in closed circuit with a screen, to minus-35-mesh. A second leach was then made in acid of the same concentration at a temperature not exceeding 110° F. After the second leach the acid was decanted and the powder washed thoroughly and then dried with a stream of air at room temperature. The final step included dry magnetic separation to remove any free iron from the grinding balls or chips from the reaction chamber.

Of the two methods, vacuum distillation produces the purer sponge, particularly with regard to hydrogen, chlorine, and magnesium content. Acid leaching is the cheapest means of removing magnesium and magnesium chloride, and vacuum-melting techniques were reported by one company whereby other impurities are reduced in the ingot produced.

QUALITY OF SPONGE PRODUCED

The quality of the sponge produced is ordinarily gaged by its hardness. As the producers' experience in controlling contamination has increased, the hardness of the sponge has gradually decreased. This increasing quality has been reflected in more rigid specifications in Government contracts for the purchase of sponge for the revolving stockpile. (See Chapter 13. Mobilization Experience, p. 150.) Initial Government specifications and the average

quality of titanium sponge submitted by Du Pont as of December 31, 1952, were as follows:

	Government specifications		Actual average quality purchased
Titanium.....percent..	99.3 (min.)	-----	¹ 99.7
Iron.....do.....	.25 (max.)	-----	.16
Nitrogen.....do.....	.03 (max.)	-----	.024
Chlorine.....do.....	.15 (max.)	-----	.10
Magnesium.....do.....	.10 (max.)	-----	.04
Brinell hardness No....	203 (max.)	-----	168

¹ By difference.

The most recent contracts were written in 1954 and specified that the hardness of the sponge should not exceed 160 Brinell hardness number. All of the contracts for revolving-stockpile purchases were amended to provide for an average maximum Brinell hardness of 145 in April 1955 and 140 in June 1955. Deliveries of sponge to the revolving stockpile in the first 6 months of 1955 averaged below 140 Brinell hardness number.

Typical average analyses of sponge submitted by two producers to the revolving stockpile in early 1955 were as follows:

	Producer A	Producer B
Iron.....percent..	0.118	0.075
Manganese.....do.....	.065	.024
Magnesium.....do.....	.038	.340
Nitrogen.....do.....	.009	.014
Chlorine.....do.....	.060	.109
Carbon.....do.....	.014	.013
Hydrogen.....p. p. m..	<50	<300

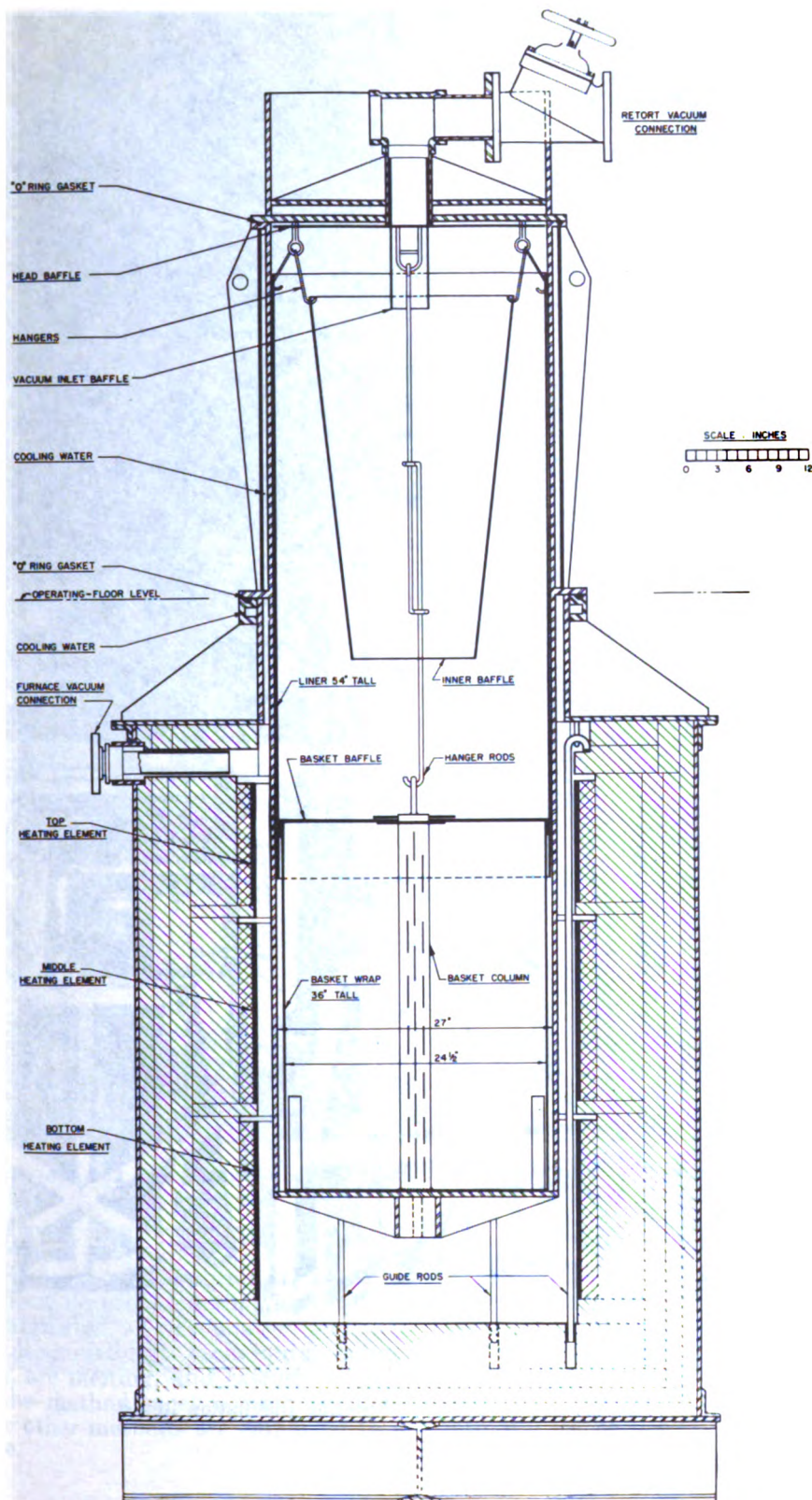


FIGURE 20.—Cross Section of Vacuum Furnace and Distillation Retort Used by Bureau of Mines.

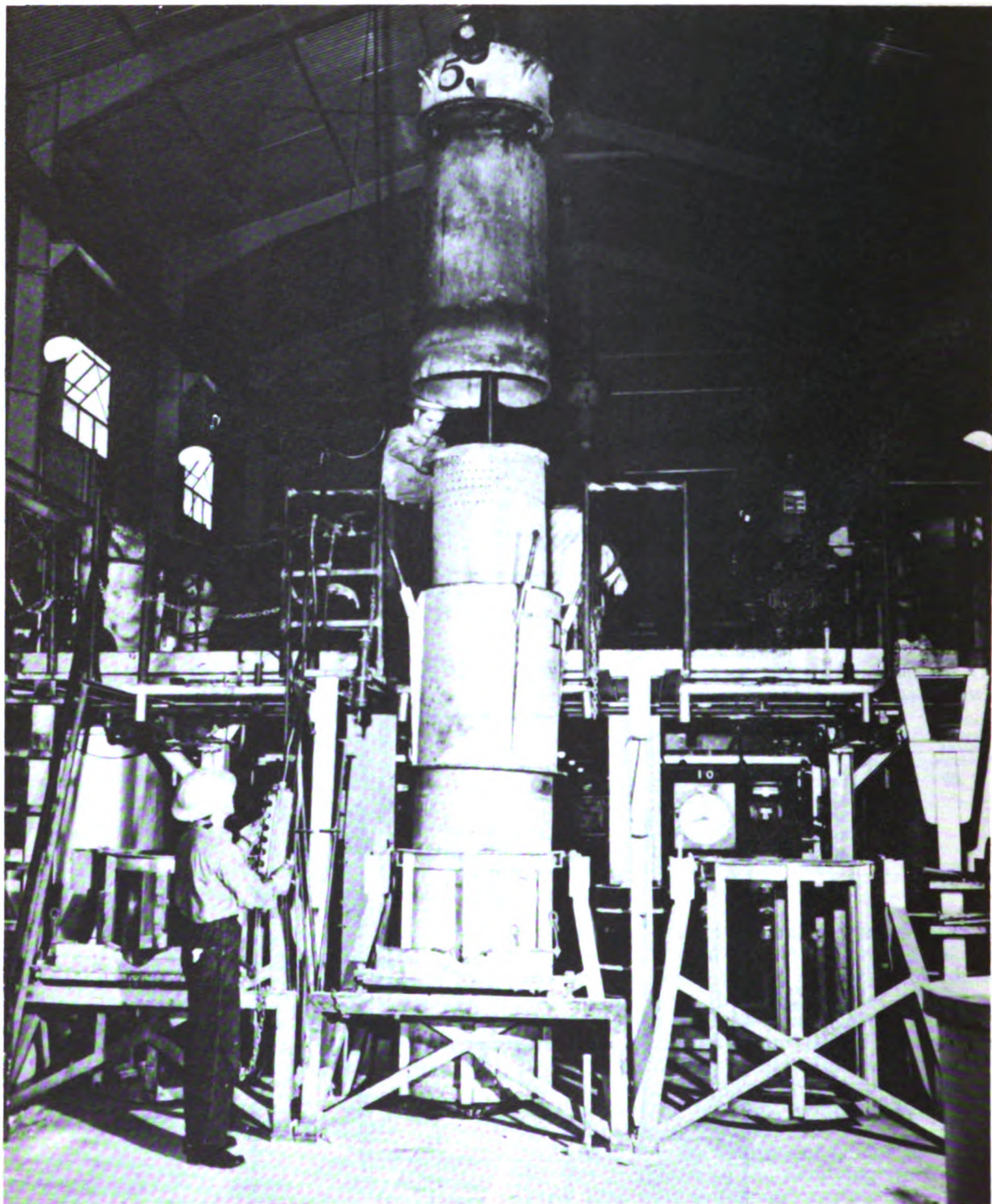


FIGURE 21.—Loaded Chip Basket Entering Distillation Retort.



FIGURE 22.—Breaking Finished Sponge Away From Basket Frame With Air Tool.

CONSOLIDATION OF TITANIUM SPONGE

Once the sponge has been obtained, ingots or some form must be prepared that may subsequently be fabricated. Consolidation methods include powder-metallurgy techniques, induction melting, arc melting, and extrusion. Arc melting is the method most commonly used, although the other methods are employed to a minor degree.

INDUCTION MELTING

Induction melts of titanium sponge are made in graphite crucibles formed from a very dense grade of graphite to minimize contamination of the melt by carbon. Contamination by atmospheric gases is eliminated during the melting by keeping the system under an inert atmosphere of helium or argon. Despite the use of a dense graphite crucible contamination

by carbon does occur, and the carbon content in the titanium may be as high as 1.0 percent. In some instances this carbon may be a desirable alloying constituent; however, if titanium carbide inclusions are present in the final ingot, any machining is extremely difficult. Because of the carbon contamination introduced by induction melting, this method is less desirable in most applications than arc melting.

ARC MELTING

The ability of molten titanium to dissolve material that might be used to contain it poses the biggest problem in melting this metal. The carbon contamination that results from induction melting is eliminated or controlled by using arc-melting techniques in which the melt is made in a water-cooled copper crucible. Use of the cooled-copper walls eliminates contamination from the container, since the molten titanium will not wet the chilled copper and rapid removal of heat solidifies the molten metal at the walls.

Melting is carried out under a vacuum or inert atmosphere of argon or helium. Vacuum melting is preferred by some companies because it removes the most hydrogen from the metal.

The metal is heated by an electric arc established between the metal in the crucible and a carbon, tungsten, or titanium electrode. If titanium is used as an electrode, it is consumed in the melting process and serves as the source of the titanium being added to the crucible. Carbon and tungsten electrodes may contaminate the molten titanium. At least one company used carbon electrodes in 1954 and claimed to have developed the method to the point where contamination by carbon was negligible; however, customer specifications are forcing this company to switch to consumable electrodes. If nonconsumable electrodes are used, the sponge or scrap is fed into the crucible through a hopper arrangement. Early difficulties in using carbon electrodes were experienced in regulating the metal feed and in properly adjusting the electrode. Local segregations of alloying materials also proved to be troublesome. Because of these early problems, the trend has been toward using double melting techniques with consumable electrodes.

Some producers have reported that the metal is more homogeneous if it has been melted twice. The process consists of compacting blended sponge into bars in suitable dies under pressures of several tons per square inch. A continuous electrode is made up during melting by heliarc welding of these compacts together as the electrode is fed into a furnace containing an inert-gas atmosphere. A water-jacketed copper crucible contains the melt as it is built up to form the first-melt ingot. A common

size of ingot thus formed at 1 plant is 12 inches in diameter by 3 feet in length, weighing about 550 pounds.

These ingots are faced off, and a large electrode is formed by welding together the required number of sections. This electrode is supported for melting by a water-cooled copper rod that also supplies the power connection. Rectified d. c. power of several thousand amperes is used in remelting this electrode into a large ingot, which may exceed 20 inches in diameter. Ingots weighing 3,000 to 4,000 pounds are not uncommon. The surface quality of the second-stage ingot is greatly improved, because some of the volatile material is removed during the first melt.

Figure 23 shows a consumable-electrode, arc-melting furnace developed by the Bureau of Mines. In general, furnaces used by the industry are of this type, but on a much larger scale. Details vary, and the exact processes used are closely held company secrets.

Some of the dangers inherent in melting titanium were dramatically brought to light by an explosion in the titanium-melting facilities of Mallory-Sharon Titanium Corp. at Niles, Ohio, on June 11, 1954. Investigation disclosed that the explosion was caused by failure of the crucible, releasing water which poured onto the molten titanium at a critical rate. Dissociation of the water produced hydrogen, which subsequently ignited and exploded.

Since that time Mallory-Sharon has installed new furnaces and has adopted methods of melting titanium by remote control. Other companies have also improved their safety precautions.

TITANIUM-BASE ALLOYS

The first alloys of titanium with other metals were produced by means of powder metallurgy. The metal powders of titanium and the alloying metal were mixed, compacted, and sintered. This method yielded fair results but was too expensive, and difficulties in diffusing high-melting metals gave inhomogeneous alloys.

At present alloys are manufactured commercially by adding the alloying metal to the titanium during melting of the sponge. Alloying metals are used to raise the tensile strength and hardness of the titanium, but they also reduce the ductility. Successful alloys have been developed with manganese, chromium, molybdenum, tin, aluminum, and iron. Alloys commercially available in 1955 and their chemical composition are listed in table 44.

UTILIZATION OF SCRAP

One problem that has troubled the titanium industry is utilization of scrap. In some fabricating operations 8 pounds of metal may be required to produce 1 pound of finished

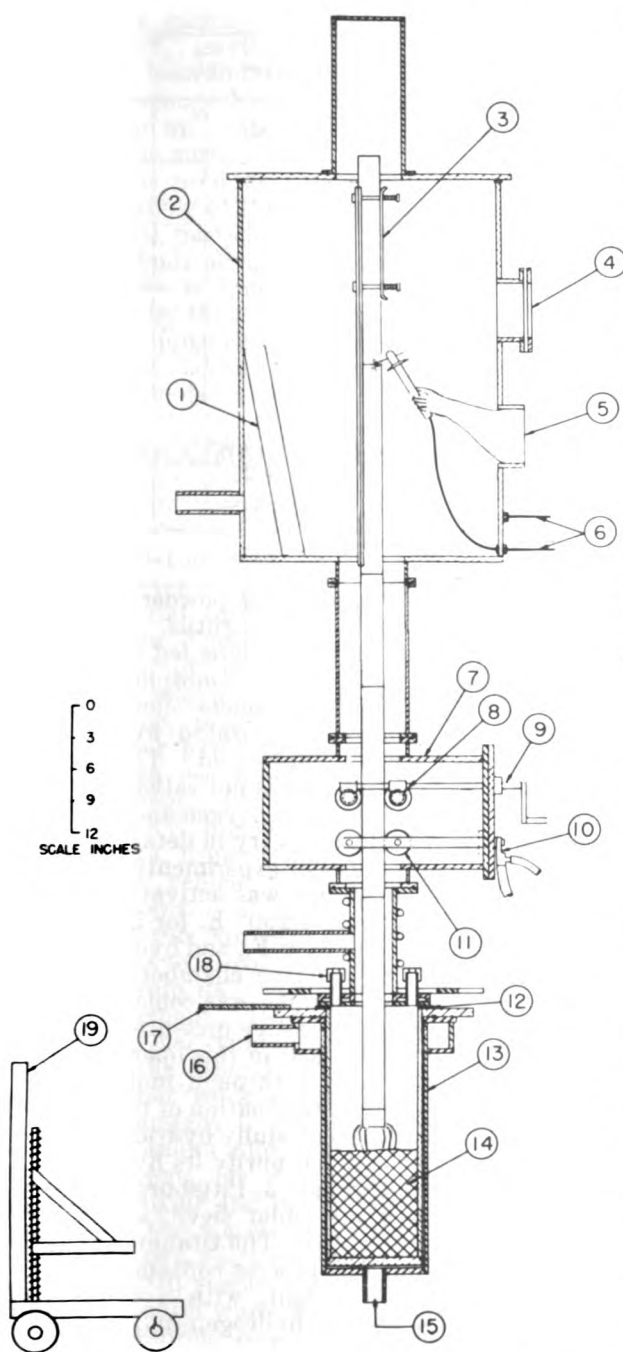


FIGURE 23.—Arc-Melting Furnace Utilizing a Consumable Titanium Electrode Developed by Bureau of Mines:

1, Electrode supply; 2, vacuum-tight tank; 3, alining guides; 4, viewing port; 5, rubber glove for bar joining; 6, welding power leads; 7, drive box; 8, mechanical drive rolls; 9, crank for electrode drive; 10, main power to electrode; 11, power-application rolls; 12, electrical insulation; 13, water jacket; 14, titanium ingot in melting cup; 15, water inlet; 16, water outlet; 17, main power to melting cup; 18, eyepiece; 19, cart for removing melting-cup assembly.

product, and about 1.7 pounds of sponge is needed to produce 1 pound of milled product. The excess material is scrap, for which there has been limited demand in the past because there is enough contamination in the scrap to raise the hardness and brittleness of the metal if it is remelted. Before 1954 most of the scrap produced was stockpiled, and this loss to the fabricator increased the price of the finished product.

Since 1954 more scrap has been utilized as the hardness of the primary sponge has decreased. Below a certain hardness the metal would be too ductile for many purposes, so it is made harder by adding oxygen or commercially pure titanium scrap. In 1955 some melters used as much as 35 percent scrap per furnace charge if the sponge was very pure. Alloy scrap still has a limited market because of the difficulty in sorting and cleaning the various grades of metal. One melting company buys all of the commercially pure scrap produced by its customers at \$1 per pound but will purchase only a limited amount of alloy-grade scrap.

POWDER METALLURGY

In early Bureau of Mines experiments the sponge was ground into powder and consolidated by sheath working at an elevated temperature. In this process the powder was packed in sealed, ductile, gastight containers and heated to elevated temperatures; the assembly was then hot-rolled. The container protected the powder from harmful gases, such as oxygen and nitrogen, during heating and working. After working, the assembly was allowed to cool, and the sheath was stripped from the finished billet. Direct contact of particles and disorganization of previous grain structures by the plastic deformation, together with the mobility of the metallic atoms afforded by the high temperature, allowed rapid diffusion and bonding among particles. As a result, solid, nonporous metal was produced without need for long sintering at high vacuum or restriction in size imposed by limitations of the pressing equipment.

Disadvantages of the method are: (1) The billet produced is inhomogeneous because no mixing occurs during the consolidation; (2) the powder is contaminated by gases more readily than sponge because of the larger surface area per unit weight involved; (3) the finer powder, which is also the most impure, tends to settle to the bottom of the container; and (4) the procedure is rather costly because of the trouble involved in sealing the powder in the cans.

Other powder - metallurgy techniques, by which a formed part is pressed directly from the powder, are becoming increasingly popular.

TABLE 44.—*Alloy constituents of commercial titanium alloys, June 1955*

Producer	Alloy designation	Alloy constituents, percent							
		Mn	Fe	Al	Cr	Mo	O	Sn	V
Mallory-Sharon Titanium Corp.	MST 3Al-5Cr			3	5				
	MST 6Al-4V			6					4
	MST 4Al-4Mn	4		4					
	MST 8Mn	8							
Rem-Cru Titanium, Inc.	A-110AT			5				2.5	
	C-110M (RC-130A)	8							
	C-130AM (RC-130B)	4		4					
	C-120AM			4					4
	C-120AV			6					4
Republic Steel Corp.	RS-120	7							
	RS-110-A	7							
	RS-130	4		4					
Titanium Metals Corp. of America.	Ti-140A		1.5-2.5		1.5-2.5	1.5-2.5			
	Ti-155A		.9-1.7	4.8-6	.8-2	.8-2			
	Ti-6Al-4V			5.5-6.5					3.4-4.5

They are discussed in more detail in Chapter 6. Fabrication of the Metal.

EXTRUSION

As yet this method has been used only on an experimental scale for the consolidation of sponge, but it may become commercially important in future. By extrusion techniques a finished shape or billet is produced by squeezing the metal through a die. The sponge is first pressed into the form of an extrusion billet that can be handled by the extrusion press. The billet is confined to a chamber, and the heat and pressure are applied to the billet until the metal is plastic enough to flow through the die. This procedure is discussed more fully in Chapter 6. Fabrication.

The advantage of this method is elimination of costly melting of the sponge and many of the intermediate steps necessary for producing a finished product. There is also less danger of picking up contamination, because the metal need not be heated to high temperatures to be extruded. A disadvantage of the method is that the metal in the shape or billet produced may lack homogeneity because there is no extensive mixing as in double melting.

PRODUCTION OF TITANIUM POWDER

Various methods are being used to produce a titanium powder for the fabrication of parts by powder-metallurgy techniques. To attain a ductile finished product, the powder should be free of oxygen, nitrogen, hydrogen, or metallic contaminants. The pure sponge is too malleable to be readily crushed or ground, so it must ordinarily be embrittled with hydrogen before grinding can be accomplished.

One method of producing powder is by the calcium hydride reduction of rutile. A mixture of rutile and calcium hydride is fed into a furnace containing a hydrogen atmosphere heated to 1,830° F. The final products—lime and fine titanium hydride—are separated by leaching out the lime with a dilute acid. The powder produced by this method is not satisfactory for all purposes, as it contains oxygen and nitrogen.

Methods of hydriding vary in detail, depending upon the producer or experimenter. In one process titanium sponge was activated for hydriding by heating at 1,290° F. for 5 minutes. It was then cooled to 840° F., and hydrogen was admitted into the reaction chamber. After a period of time the chamber was cooled to room temperature under a positive pressure of hydrogen. The hydrogen used in this operation was purified by bubbling it through molten magnesium to prevent contamination of the sponge. The Clevite Corp. successfully hydrided sponge at 1,070°-1,250° F. To purify its hydrogen, it passed the gas through a Pittsburgh Lectro-dryer, through a molecular sieve, and finally over hot titanium chips. The titanium hydride that results from this process contains 3-4 percent hydrogen by weight, with a theoretical maximum of 4 percent hydrogen in TiH₂. The hydride is ground or crushed to a powder, and the hydrogen is driven off.

Hydrogen may be removed by sintering the pressed-powder part under a vacuum or by separate vacuum treatment at temperatures up to 1,500° F. Ordinarily both processes are employed, as it is difficult to remove all of the hydrogen.

If scrap is to be used as the source material of the powder, all surface contamination must be removed before embrittlement. Scrap has

been embrittled and pulverized by milling the metal in a mercury bath. The mercury was distilled off, leaving a high-purity powder. There has been some success in powdering non-hydrated sponge by pulverizing the sponge in an attrition mill which employs titanium plates to minimize surface contamination. Water at 40° F. was used as a protective medium to prevent galling of the powder to the plates.

The final particle size attained by any of these methods should be 30- to 100-mesh, as finer powder is very reactive and easily contaminated by the atmosphere. Powder that is finer than minus-300-mesh must be kept covered with water, because the powder is reactive enough to be dangerous.

PRODUCTION OF PIGMENTS

HISTORY

In the latter part of the 19th century 2 attempts were made to use titanium minerals as a material for paint. J. W. Rylands, a Birmingham (England) varnishmaker, obtained a cargo lot of ilmenite from the Norwegian mines of a company that went into liquidation in 1869; he, perhaps, was the first to use titanium for paint-pigment purposes, but his idea was to use the powdered ilmenite as a black pigment. In 1870 Dr. John Overton of Louisville, Ky., introduced titanium compounds as pigments, using a mixture of rutile with a bituminous vehicle as a resistant paint for ships' bottoms.

In 1908 the Norwegian Government began experiments to discover a method of extracting titanium from its ores and to find major uses for the element. However, the real history of commercial titanium pigments probably began in the laboratory of Dr. A. J. Rossi, whose earlier work on titanium-bearing ores had led gradually to the commercial manufacture of titanium alloys in 1906. Continuing his experiments, Dr. Rossi succeeded in making an impure oxide and in 1908 demonstrated the opacity of the material and thus glimpsed its suitability as a paint pigment.

About 1910 research into methods for producing titanium white was stimulated by legislation in Europe directed against the use of white lead. Finally the experimenters in America and Europe, combining their resources, adopted a standard method of extracting titanium oxide from ilmenite with sulfuric acid. Associated with Dr. Rossi in the United States was L. E. Barton, and the concurrent discoveries in Norway were made by Gustav Jebsen, V. M. Goldschmidt, and J. P. Yeager.

In 1916 the Titanium Pigment Co. was incorporated and began to build a factory

adjoining the works of the Titanium Alloy Manufacturing Co. at Niagara Falls, N. Y. Operation of this factory was delayed until after the armistice in 1918, when commercial production was begun. The National Lead Co. purchased a substantial interest in the new enterprise in 1920, and by 1922 domestic demand exceeded the limited capacity of the Niagara Falls factory, necessitating importation of titanium pigments from Europe. A second and larger factory was built in St. Louis during 1923.

At first the only titanium pigment produced was the barium-base grade known as "Titanox"—B. Production of calcium-base pigments ("Titanox"—C) was begun at Niagara Falls in 1925, but in 1928 this work was transferred to St. Louis, where hitherto only barium-base pigment had been produced. For a time the Niagara Falls plant concentrated on the production of pure titanium dioxide ("Titanox"—A), but later this operation too was transferred to St. Louis also. In 1928 the Commercial Pigments Co. began operations in Baltimore. From this point onward productive capacity in the United States expanded rapidly. (See Chapter 7. Structure of the Industry, for the further development of the titanium-pigment industry.)

PRODUCTION

As shown in figure 24, the essential steps in producing titanium pigment by the sulfate process are: Digestion of the ore, reduction of the iron, crystallization and separation of ferrous sulfate, hydrolysis of the titanium, solution to precipitate hydrous titanium oxide, calcination, and grinding. In actual practice methods of preparing titanium pigments vary widely, and the exact way in which these steps are carried out is closely guarded company information.

The final pigment, titanium dioxide, comes in two forms—rutile or anatase. Both forms crystallize in the tetragonal system, with the difference between the two occurring in the length of the *c* axis. Anatase has a refractive index of 2.52, while the index of rutile is 2.72, thus giving rutile a much greater hiding power than anatase.

One pigment producer chlorinates a mixed product of ilmenite, rutile, and leucoxene to produce titanium tetrachloride and, through a series of reactions, converts this to titanium dioxide. However, most of the plants now operating manufacture titanium dioxide from ilmenite by the sulfate process.

The concentrated ilmenite is ground to 95 percent minus-325-mesh and is digested with sulfuric acid. This digestion may take place in batch or continuous attack, the latter method

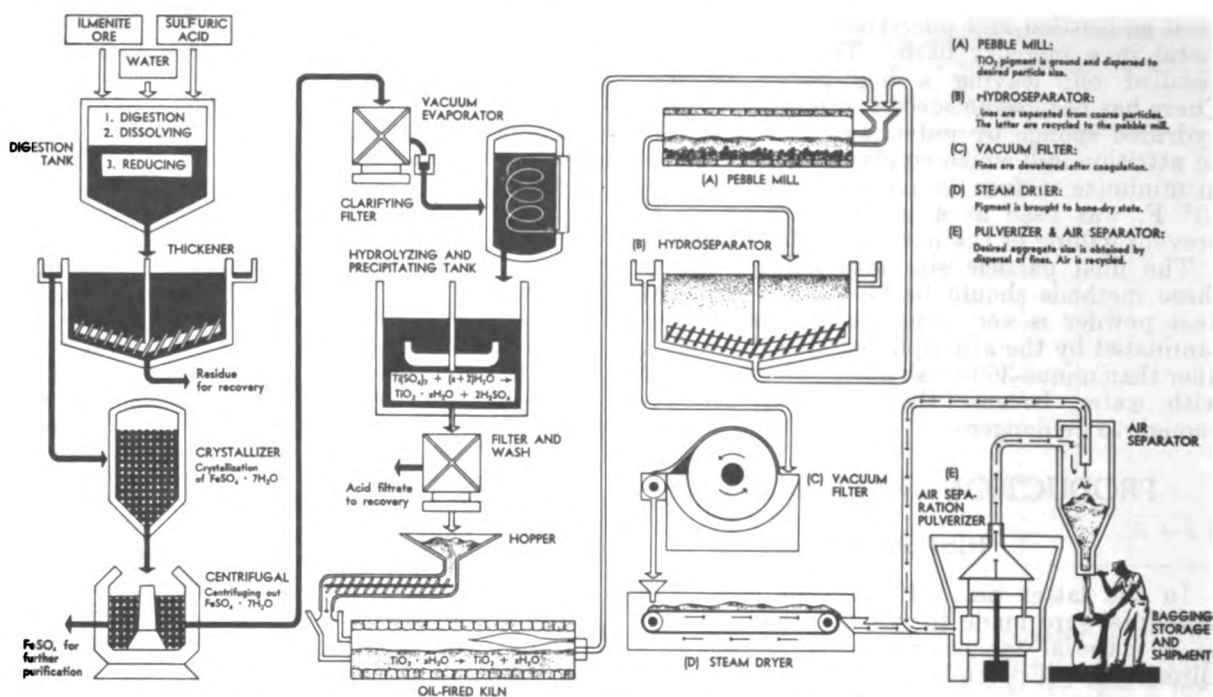


FIGURE 24. Schematic Flowsheet for Manufacturing Titanium Dioxide Pigments by Sulfate Process.

(Courtesy E. I. duPont de Nemours & Co., Inc.)

being employed in some plants in England and the former in the United States. The attack tank typically is about 12 feet in diameter and 30 feet in height and may be closed or open to the atmosphere. If the tank is closed, the reaction takes place under pressure with the tanks vented through stacks. A typical charge consists of 50,000 pounds of 66° B. sulfuric acid, 40,000 pounds of ilmenite, 175 pounds of antimony trisulfide, and 175 gallons of water to bring the acid concentration to 90 percent sulfuric acid. After all the ingredients have been added to the tank, the temperature is raised to 230° F. by passing in steam, although in most instances it is not necessary to add steam because of the exothermic nature of this reaction. Once started, the reaction is quite violent and highly exothermic, going to completion in 3–15 minutes. The resultant mixture is a honeycombed solid mass, which must be allowed to cool before water is added to put the soluble material into solution.

The digested slurry is treated with coagulating agents, consisting of a soluble sulfide (sodium sulfide) and an organic proteinaceous material (glue), and pumped to a settling tank. The digested liquor is decanted, the sludge going to a rotary filter to recover any additional liquor. The decanted liquor goes to reduction tanks, where scrap iron is used to reduce all the iron to the ferrous state. The amount of scrap required for this reduction varies with

the ore, but at 1 plant it amounts to 250 pounds of scrap for every ton of pigment produced. In some plants the scrap is added directly in the batch-attack tanks.

Essentially the products in solution at this point are titanyl sulfate ($\text{TiOSO}_4 \cdot 2\text{H}_2\text{O}$) and ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$). About two-thirds of the ferrous sulfate or copperas is crystallized out of solution by cooling the liquor to 50° F. in a vacuum. The crystals are removed in a centrifuge and washed further in a centrifuge to remove any adhering titanium solution.

The solution is pumped to clarification, where it is filtered in some fashion. In one plant this is accomplished by passing the solution through ordinary sand filters. Other companies filter the solution through diatomaceous earth filters and then through tube filters of porous carborundum.

The solution now contains 140 to 150 grams of TiO_2 , 30 grams of iron, and 65 to 70 grams of free acid per liter. Evaporation in a lead evaporator concentrates the solution, and the concentrate passes to a hydrolyzing and precipitating tank. Here the soluble titanyl sulfate is converted to insoluble titanium hydrate, $\text{TiO}(\text{OH})$. The addition of rutile or anatase seed before precipitation determines the type of pigment that will be crystallized. Also, careful control must be maintained of the temperature, acid concentration, concentration of titanium

sulfate, and time of boiling in the precipitation process. Anatase must be boiled for 6 hours, whereas rutile requires only 3 hours.

The precipitated pigment is pumped to a cooling tank and then to a system of filters. Iron sulfate and other soluble material are removed by filtration and washing. The last of the iron is removed by repulping the filter cake, reducing any ferric iron with titanous sulfate, and afterward filtering and washing.

The repulped second filter cake is treated with a conditioning agent to prevent sintering and permit use of the proper temperature during calcination. Potassium carbonate is the conditioning agent for anatase, while sodium and potassium carbonate or lithium and zinc sulfate may be used for rutile. The concentrated slurry passes through a rotary, oil-fired calciner, where the temperature at the input end is about 680° F. and the discharge temperature is about 1,800° F.

After the material has spent approximately 8–12 hours in the calciner, it is pulverized and quenched in water. The slurry thus formed is treated with sodium hydroxide and pumped to a hydroseparator. (At one plant a centrifuge is used for classification.) Fines flow over the top of the separator, and the grits are returned to the ball mill for further grinding. The fines go to a thickener, where they are coagulated by adding calcium chloride. The thickened material is fed to a filterpress, dewatered, and dried and reground ready for use.

The pigment produced may be employed as such in paints, ceramic enamels, paper, and linoleum and for other uses, or it may be extended for use in paints by further treatment with calcium sulfate.

PRODUCTION OF NON-TITANIUM-BASE ALLOYS AND CARBIDE

FERROALLOYS

HISTORY

The first commercial application of the element titanium was as an alloy additive for iron and steel. The credit for establishing the use of titanium as an alloying material belongs largely to Auguste J. Rossi, a French metallurgist resident in the United States. Rossi's first experiments with titanium were in connection with attempts to produce iron from titaniferous ores in a blast furnace. His work on the smelting of titaniferous ores led him to try to produce titanium-iron alloys by reducing iron and titanium together in the blast furnace, but he was unable to make a high-titanium alloy in this fashion. Working with an electric furnace at high temperatures, he at last succeeded in evolving an economical process for manufactur-

ing high-titanium alloys. The Titanium Alloy Manufacturing Co. of Niagara Falls, N. Y., was formed in 1906 to exploit these and other titanium products.

Rossi appears to have produced ferrotitanium by an industrially practicable process before 1895, but the possibilities of the new alloy were slow in obtaining recognition. The first extended application of ferrotitanium began at the Maryland Steel Works in 1907, where it was used for purifying steel. It was used for treating cast iron at the car-wheel foundry of the Norfolk & Western Railway at Roanoke, Va., in 1908. Since then titanium has been finding increasing use in the iron and steel industry.

PRODUCTION OF FERROALLOYS

Three major grades of master alloys of titanium with iron are made for use as iron and steel additives: High-carbon, medium-carbon, and low-carbon ferrotitanium.

The high-carbon ferroalloy contains 7–8 percent carbon and 15–17 percent titanium, although a high-carbon grade is produced in Europe with 10 percent carbon and 40 percent titanium. The carbon in this grade is present as titanium carbide and graphite. High-carbon master alloys are made by reducing ilmenite with coal or coke in a single-electrode arc furnace, employing a high-current density. The alloy is tapped from the furnace onto cast-iron castbeds, forming thin ingots. These ingots may be crushed for use.

Medium-carbon ferroalloys contain 3–5 percent carbon and 16–20 percent titanium. This master alloy is made in the same fashion as the high-carbon ferroalloy, except that some rutile is added to refine the metal by oxidizing some of the carbon. High and medium carbons are used to deoxidize steel or to control the grain size. These additives do not have the effect of stabilizing the carbon or nitrogen in the steel.

Low-carbon master alloys have 0.03–0.1 percent carbon and 20–45 percent titanium and come in 2 general classes. One class contains 20–29 percent titanium and is hard to crush, and the other class contains 33–45 percent and is somewhat friable. These alloys are made by the aluminothermic reduction of ilmenite and rutile. An excess of aluminum is required in this reduction, so the alloy contains aluminum. One company produces a very low carbon 27–32 percent titanium alloy by a combination of aluminothermic reduction and further purification in an electric furnace. In 1954 a 70-percent-titanium, low-carbon alloy was put on the market. It is of very high purity and is made from titanium metal and scrap iron. Low-carbon ferroalloys are used for stabilizing carbon

and nitrogen in plain and alloyed steels. They may also be used to deoxidize low-carbon alloy-steel castings and as a source of titanium in precipitation-hardening alloys.

In addition to these three main classes of master alloys, an iron-silicon-titanium alloy is produced for additions to low-alloy steel when both silicon and titanium are desired. There are various types of ferrosilicon: One alloy has 20 percent titanium and 20 percent silicon and has a low melting point; another alloy has 20 percent silicon and 27–30 percent titanium and has a higher melting point; a third alloy has 45 percent silicon and 45 percent titanium. These alloys may be made in an electric-arc

furnace or by aluminothermic reduction. In the aluminothermic reduction the silicon combines with the titanium, making the ore more readily reducible. Consequently, the alloy contains less than 1 percent aluminum and less than 0.1 percent carbon. The electric-arc furnace employs a high-grade ferrosilicon or silicon carbide as a reducing agent, thus yielding a product with up to 0.5 percent carbon. Ilmenite, rutile, or a mixture of the two may be used as a source of the titanium, depending upon the percentage of titanium desired in the final product.

The composition of some of these master alloys are summarized in table 45.

TABLE 45.—Composition and melting point of some typical ferrotitanium alloys

Master alloy	Typical composition, percent					Melting point, °F.
	Ti	C	Si	Al	Fe	
Ferrotitanium:						
High carbon	15–19	6–8	2–3	1–2	Balance	2, 650
Medium carbon	17–21	3–5	2–3	1–2	do.	2, 700
40 percent low carbon—regular	39–42	0. 03–0. 1	2. 5–4	7. 5–9. 5	do.	2, 550
40 percent low carbon—low aluminum	39–42	. 03–0. 1	10–13	3–5	do.	2, 800
40 percent low carbon—low silicon	39–42	. 03–0. 1	. 4–1	11–13	do.	
25 percent low carbon	26–29	. 03–0. 1	2. 5–3. 5	5–7	do.	2, 735
Foundry	27–31	. 03–0. 1	20–24	. 5–1. 5	do.	2, 841
Silico—titanium	44–47	. 03–0. 1	42–45	1. 5–3	3.5–4.0	
Carbortam	15–21	4. 5–7. 5	2–4	1–2	Balance	2, 650

SOURCE: Titanium Alloy Manufacturing Division, National Lead Co., Chemical and Physical Properties of TAM Products.

ALLOYING TITANIUM WITH IRON AND STEEL

As mentioned previously, titanium is usually added to iron and steel in the form of master alloys; however, additions may be made in the form of a titanium mineral or almost pure metal. Du Pont in 1955 announced production of a new grade of titanium metal to be used specifically as an additive to ferrous and nonferrous alloys. It is designated as titanium metal, grade NDA, and comes in the form of pellets or fines containing 97 percent minimum titanium and 3 percent maximum iron. Rutile or a rutile-ilmenite blend may also be added directly in the manufacture of some steels.

If ferrotitanium is to be used as a deoxidizing agent, it is added to the ladle. For this use, the alloy is crushed into $\frac{3}{4}$ - to 2-inch lumps and packed in bags. The bags or the unpacked lumps are thrown into the molten stream going into the ladle. The addition should be started when the bottom of the ladle is covered with steel and completed just before the slag flows from the furnace. If a tilting furnace is used, the slag should be held back until most of the steel is tapped, as the ferrotitanium becomes ineffective if it is covered with slag.

In cupola-melted cast iron, ferrotitanium in the form of $\frac{1}{8}$ -inch granules is poured slowly into the stream flowing from the cupola taphole. The treated iron in the ladle is stirred and carefully skimmed to remove the dross before casting. A 50-percent recovery of titanium in the cast iron is considered good. In crucibles, electric furnaces, or air furnaces ferrotitanium is added to the melted cast iron by stirring the alloy into the slag-free surface of the bath. In stainless-steel melting in an electric furnace, titanium should only be added after the melt has been thoroughly deoxidized. Ferrotitanium is added to the ladle in open-hearth practice after the steel has been deoxidized with 3–4 pounds of aluminum per ton.

OTHER NON-TITANIUM-BASE ALLOYS

Titanium is finding increasing use as an alloying element with aluminum. The addition of titanium to aluminum gives a marked grain refinement and a consequent increase of strength by affording a greater number of nuclei around which the aluminum crystallizes. Titanium may be added in the form of a master alloy of aluminum containing 5–6 percent titanium or

in the form of K_2TiF_6 . A 2.5- or a 5-percent titanium master alloy is added to aluminum casting melts. The presence of titanium in aluminum destined for use as an electric conductor is undesirable, since even very small amounts lower the conductivity.

Titanium has an age-hardening effect upon copper, so that small amounts of titanium added to copper produce a large increase in tensile properties. Titanium is added as lumps of a titanium-copper master alloy to the molten copper. These master alloys contain 15–80 percent titanium, although the most popular grade contains 28 percent titanium.

In general, nickel and its alloys are hardened by titanium, and it imparts improved mechanical strength to nickel at high temperatures. Titanium has been found valuable in making sound nickel welds, as it acts as a deoxidizer or degasifier in welding. Master alloys of titanium-nickel are available in powdered form containing 30–70 percent titanium.

CARBIDE

Titanium carbide is an interstitial compound having high hardness, low density, excellent wear resistance, and good resistance to oxidation. It may be used as a tooling material or as a cermet where it is necessary to have strength and shock resistance at high temperatures.

Generally, titanium carbide is prepared by heating a mixture of rutile or manufactured TiO_2 and carbon to a temperature above $3,270^\circ F$. in a vacuum or in an atmosphere of hydrogen. One company states that it is necessary to use manufactured TiO_2 to produce a very pure carbide. Also, very pure titanium carbide may be made by decomposing a titanium tetrachloride-hydrogen mixture on a carbon filament at $3,090^\circ F$. After the carbon has been completely absorbed, the carbide is annealed in a vacuum at $3,810^\circ F$.

One of the major producers makes titanium carbide by the menstruum process. In this process titanium dioxide, iron, and carbon are induction-heated in a graphite crucible to a temperature exceeding $4,800^\circ F$. to effect carburization in solution. When all of the material has reacted, it is cooled, and the button formed is broken up and treated chemically to remove the iron.

In the production of tooling materials nickel or cobalt is used as a binder to hold the titanium carbide particles together. However, if powder-metallurgy means of fabrication is used, no binder is necessary, and the method of producing the carbide differs somewhat. Graphite and titanium hydride are mixed in stoichiometric proportions and heated in a carbon crucible under a hydrogen atmosphere to $3,452^\circ$ – $3,812^\circ F$.

The powdered carbide produced is ground and screened to the desired size and then pressed and sintered into the desired shape.

Whatever method is used, it is impossible to make a titanium carbide containing the theoretical carbon content of 20.05 percent. The combined weight of carbon rarely exceeds 19.4 percent.

PRODUCTION OF WELDING-ROD COATINGS

Although ilmenite and manufactured TiO_2 may be used as a source of titaniferous material in welding-rod coatings, rutile is considered to be the most desirable material for this purpose, and for certain types of coatings these other materials cannot be substituted for rutile. Manufactured potassium and sodium titanates are also being used increasingly in welding-rod coatings. (See the section on Welding-Rod Coatings in chapter 1 for a further discussion of the substitution of one titaniferous material for another in welding-rod coatings.)

All constituents of the coatings vary widely with the manufacturer. Foote Mineral Co. manufactures a coating that contains, in addition to other fluxes and binders, 3.94 percent ferrotitanium, 5.31 percent rutile, and 8.26 percent calcium titanate. Another typical composition is: 36 percent TiO_2 , 36 percent ferric oxide, 18 percent sodium carbonate, 9 percent silica, and 0.5–5.0 percent calcium hydroxide.

At one time the rods were coated by merely dipping them in a slurry of the coating compound, but in 1955 the rod and coating were extruded from a press. The ingredients of the coating are first charged into a mulling machine for mixing. After water is added, the mixture is mulled several minutes to a stiff consistency and then pressed into cylindrical slugs about 18 inches in length and 10 inches in diameter. These slugs are put into the cartridge chamber of an extrusion press; and the cut welding rods are fed into the coating die, where they are coated to a uniform thickness with extruded flux.

After extrusion the rods are dried at $250^\circ F$. for 20 minutes and then fired at $1,175^\circ F$. for 20 minutes. This removes all the water from the coating, eliminating the danger of the coating exploding when heated by a welding torch.

PRODUCTION OF CERAMIC MATERIAL

The basic material used in porcelain enamels is frit, which is composed of fluxing oxides, refractory oxides, opacifiers, and glass formers. Titanium dioxide functions as an opacifier in

the enamel, as do oxides of antimony, zirconium, and tin.

Either a batch or continuous method is used in producing frit, with the batch method passing into obsolescence. In the batch method the various components are mixed and placed in a preheated frit smelter. After the temperature has been raised to 2,300° F., the mixture becomes molten. It is then discharged into a tank of water, which causes the suddenly cooled, vitrified material to shatter.

In the continuous method the constituents are placed upon a belt, which carries them into the furnace. The material passes into the furnace, melts, and is tapped continuously from the bottom of the furnace. The melt passes between water-cooled rollers, which cause the vitrified melt to shatter. These vitrified particles (frit) are milled in a ball mill to about minus-200-mesh to form the enamel slurry. The slurry is sprayed on metalware and fired at a temperature below the smelting range. Before the metal can be enameled a ground coat containing either nickel or cobalt must be applied, or the enamel will not hold.

In the case of titanium enamels, the frit comes from the smelter clear because the glass has been quenched so quickly that the titanium does not have time to precipitate out of solution; however, during firing the titanium does have time to precipitate out of solution, yielding an enamel that has great covering power.

In addition to the use of titanium in enamels, it also finds use in other ceramic applications. Rutile is used as a coloring, crystallizing material in certain pottery glazes and acts as a colorant in ceramic bodies, such as floor tile and dinnerware. The amount used for these applications is relatively small.

Within the past 20 years a new field of high dielectric ceramics has been developed, based upon compounds of titanium dioxide. The most frequently used material is barium titanate, which finds application in many high-dielectric ceramic products as well as in uses where its piezoelectric properties are important.

The barium titanate and the other components of the ceramic body are mixed with water

or some other liquid and formed into the desired shape. This forming may be accomplished by any of the standard ceramic methods of extrusion, jigging, pressing, soft-mud molding, slip casting, or machining. The shapes are dried and then fired at about 2,300° to 2,500° F. or until vitrification takes place. The finished capacitor may be fabricated into a wide variety of shapes and may be water-proofed by means of applying lacquer or a similar coating.

PRODUCTION OF FIBERGLASS

To produce fiberglass titanium in the form of rutile is added to the molten glass in the furnace. When the proper temperature is reached, the glass is dropped through a small orifice in the bottom of the furnace and blown with air or steam. The filaments produced are wound onto a plastic tube, where the tension of winding draws the hot filaments into smaller diameters. Ilmenite or Sorel slag may be used for this purpose, but rutile or manufactured titanium dioxide must be used for fiberglass that is to find application in electrical insulation. The iron present in ilmenite and slag lowers the electrical resistance of the finished product.

PRODUCTION OF SYNTHETIC GEMS

Synthetic gems of superior refractive index are produced from manufactured titanium dioxide. The gems are made by fusing titanium dioxide powder in an oxyhydrogen flame. The fused material crystallizes progressively into a cylindrical boule, which is then cut into the desired stones. Various colors are produced by varying the impurities present. A blue crystal may be made by adding about 1 percent Ta_2O_5 or Nb_2O_5 and then heating the boule in an oxidizing gas. According to one company, strontium titanate yields a boule with the color and brilliance of a diamond. The index of refraction of the synthetic gem is actually higher than that of a diamond, being 2.70 compared to 2.41 for the diamond; however, it is considerably softer.

CHAPTER 6. FABRICATION OF METAL

GENERAL

Much emphasis has been placed upon solving the many problems inherent in fabricating titanium, because only after these problems have been solved will titanium be accepted widely by industry. It is of interest to note how the price of the metal increases as it goes through various processing steps: The cost of sponge in April 1955 was \$3.95 per pound, the cost of semifabricated metal (with extras) averaged \$10 to \$17 per pound depending upon the shape, and the cost of the finished, fabricated part may exceed \$100 per pound. One of the main reasons for the high cost of the finished product is that most of the parts produced have been turned out on only a small scale rather than being manufactured in any quantity. As the demand for titanium parts increases, the price of the fabricated part should decrease markedly.

The four companies that melt titanium commercially manufacture and sell mill products, such as sheet, bar, plate, forging billets, and wire. Another company produces forging billets and extrusion billets on a small scale for its own use. (See Chapter 7, Structure of the Industry.) The mill products are purchased by various companies, which fabricate them into finished products by standard techniques, such as welding, grinding, machining, and forging. Most of the fabricators are airplane manufacturers, because in 1955 the chief use of titanium metal was in aircraft.

HOT AND COLD WORKING

The cylindrical ingot, produced by the melting furnace, can be rolled, hammered, pressed, or extruded into blooms, billets, or slabs. These can then be worked into plate, sheet, strip, bars, rods, forgings, tubes, or special shapes.

Early experiments revealed some of the peculiar characteristics of forming titanium and titanium alloys:

1. Many forming operations can be carried out at room temperatures.
2. Some titanium-base, high-strength alloys must be formed at elevated temperatures if severe bends are involved.

3. An intermediate group of alloys can be formed at room temperature, but the operation is best carried out at higher temperatures.

4. The best results in forming titanium are obtained if the operation is carried out slowly, as titanium has the property of resisting rapid deformation.

In forming titanium sheet it has been found to be advantageous to heat the sheet to 500°–800° F. for operations such as brake forming, drop-hammer forming, reverse bending, spinning, and deep drawing. Advantages over cold forming are: Less power is required, springback of the formed piece is reduced, tighter bend radii are obtained, and scrap loss is reduced.

At higher temperatures, titanium introduces a special problem in that it absorbs various gases, with consequent embrittlement and loss of ductility. Above 300° F. hydrogen is absorbed, oxygen is absorbed above 1,300° F., and nitrogen is taken into titanium above 1,500° F. Nitrogen is less active than oxygen, and hot titanium will preferentially absorb oxygen if both gases are present in the atmosphere.

From this it may be seen that it is desirable to heat titanium metal and alloys in reducing atmospheres free of hydrocarbons or hydrogen. Oxidation of the metal is manifested by scale forming on its surface. Below normal forging temperatures of 1,750° F. the rate of scale formation is not rapid, so that the metal need not be covered by an inert atmosphere unless it is held at elevated temperatures for long periods.

No direct flame should be used to heat the metal, although heating should be done as rapidly as possible. Three methods of heating are in general use: Induction heating (for small parts), resistance heating, and salt baths. Salt baths are recommended by some companies engaged in forging, because rapid heating results with no exposure of the metal to air or carbon during heating. The composition of the salt bath may be 90 percent BaCl_2 , 10 percent NaCl .

In general, titanium works like steel, so that in 1955 most forming operations were carried out on machines designed to form steel. However, because of the tendency of titanium to gall and seize, its affinity for various gases, its low thermal conductivity, and its lower coefficient of thermal expansion, special considerations must be noted before the metal can be hot- or cold-worked on steel-forming equipment.

FORGING

Stock for forging must be of the highest quality and uniformity, because any lack of ductility in the stock cannot be overcome by the forging process. The surface of the stock should be free of cracks, laps, seams, or scratches, although Rem-Cru Titanium, Inc., has found that, unlike steel, these surface defects do not open up during forging. Surface blemishes should be removed before and after forging by methods such as sand blasting, chipping, grinding, or machining. To detect these blemishes, the metal may be pickled in a hot mixture of 30 percent HNO_3 , 2-3 percent HF, and 68 percent water.

The dies used must be of the highest quality, because any toolmarks transferred to the forged parts may cause difficulties in later operations. These marks are hard to remove in later scaling or pickling processes. Also, titanium shrinks less than aluminum or steel during cooling, so special account must be taken of this property in die design.

Lower temperatures and about the same pressures are required to forge titanium as to forge steel. Because of the ability of titanium to resist sudden deformation, pressures should be applied slowly.

Heated parts awaiting forging should be placed on clean, refractory-brick rails. Care must be exercised in handling the hot metal because of its tendency to pick up contaminants, such as carbon, which alter the characteristics of the metal.

The amount of heat required to forge titanium depends upon the size of the part and its alloy composition, but ordinarily temperatures do not exceed 1,800° F. It is best to forge the part halfway and then to reheat it and finish-forging, rather than to forge the part until it is too cool to work. Rem-Cru A-55 and A-70 should be heated to 1,650° F. for initial forging and to 1,300°-1,400° F. for finish forging. Rem-Cru C-130AM, an alloy specially designed for forging, is heated to 1,750° F. $\pm 50^\circ$ initially and finished at a minimum temperature of 1,350° F. Smaller parts of this alloy are heated to starting temperatures of 1,650° F.

After the part has been forged, it should be annealed or stress-relieved. Rem-Cru A-55 and A-70 are stress-relieved by heating the metal to 1,100°-1,200° F. and keeping it at this temperature for 1 hour. C-130AM is stress-relieved at 1,300° F. for 1 hour.

ROLLING

Rolling is used for producing semifabricated products, such as sheets, plates, strips, and

bars. For the purpose of ordering, sheet is all widths of the rolled product over 24 inches and thicknesses under 0.1875 inch. Strip is all widths under 24 inches down to $\frac{3}{8}$ inch and thicknesses up to and including 0.1875 inch. Plate comes in widths greater than 6 inches (1 company specifies 10 inches) and in thicknesses greater than 0.1875 inch. Widths of plate under 6 inches (or 10 inches) are considered to be bar.

Bar stock for rolling may be produced by forging ingots to intermediate size, or a round stock for this purpose may be extruded. In either instance, the stock has to be well cleaned before it can be used in the rolling mill to provide a good finish on the final product.

After conditioning the forged bars are rolled to size at about the same temperatures as are used for small forged parts.

Low-hardness ingot must be used to produce sheet to insure maximum ductility. Titanium ingots are conditioned by grinding or machining and then press-forged into slabs 4 to 8 inches thick. The slabs are reconditioned and rolled into $\frac{1}{2}$ - to 1-inch-thick sheet bars on a 2-high roughing mill at 1,500°-1,750° F. This sheet bar is further reduced by 5 to 7 passes through a hot strip mill to a thickness of 0.1-0.125 inch. One semifabricator uses a recoiling reversing hot mill for this operation.

Some producers then cut up this sheet into hot-rolled strip. The strip is intensively inspected, reconditioned, and then pack-rolled on handmills. To pack-roll, the titanium sheets are piled on top of each other, and the whole stack is rolled together. The top and bottom sheets of the stack are either stainless steel or nickel to provide protection against the air. The end rolling temperature may be 1,100°-1,300° F. Pack rolling produces a sheet with a minimum thickness of 0.015 inch and a maximum width of 48 inches.

Backward and forward tension on the sheet, brought about by reverse rolling, cuts down directionability of the surface properties, and cross rolling also helps to eliminate any directionability.

One company cold-rolls the coils produced by its reversing hot mill and uses a 4-high cold mill with 16, $\frac{1}{2}$ -inch-diameter working rolls for this purpose. If thinner sheet is desired a Sendzimir mill with 1-inch-diameter rolls is employed. Sheet that develops cracks along the edges is removed from the mill, sheared, annealed, pickled, and then finished on a cold hand mill.

By 1955, sheet having a thickness of 0.016 inch and strip having a thickness of 0.004 inch had been produced.

The diffusion layer formed during rolling must be removed before the sheet can be used.

This layer is a thin, brittle, outside layer, rich in oxygen, that breaks during bending. Since titanium has the property of propagating surface cracks at depth (known as notch fatigue), it is very important to remove this layer, which is about 0.001 inch thick on each side of the sheet.

As an example of the thinness to which titanium may be rolled, the American Silver Co., Inc., produces titanium foil down to 0.0005 ± 0.0001 inch thick and 8 inches wide. It accomplishes this on 2-high, 4-high, and Sendzimir rolling mills. The Sendzimir is a cluster-type mill capable of rolling at speeds of 300 f. p. m.

EXTRUSION

It has been found that titanium lends itself well to extrusion. Titanium fills the extrusion die and seems to extrude better than steel. Extrusion is continuous shaping of a material by forcing it through a die under pressure. Heat and high pressures are used to cause plastic flow of the material. Extrusion eliminates costly machining of shapes from bar stock, so chip waste is reduced. The cost of extruding titanium is about one-fourth that of making the same shape by machining. Extruded shapes compare favorably in strength to similar forged parts. H-shapes, T-shapes, rods, bars, sheets, and similar shapes can be successfully extruded.

For extruding titanium, 1 company uses a 1,650-ton horizontal hydraulic press that had been designed to extrude aluminum. The diameter of the container for the ingot is $5\frac{1}{2}$ inches, while the diameter of the ingot itself is 5 inches. The dies are designed to block off entry of the material adjacent to the container wall, so that the surface of the billet does not enter the die.

Billets to be extruded are heated to between $1,700^{\circ}$ and $1,900^{\circ}$ F. in a salt bath. A pressure of 138,000 p. s. i. is applied to the base of the billet. Runout speeds must be fairly high and constant to prevent the titanium from building up at certain points on the die and thus ruining the die. The speeds used are ordinarily 500–1,500 f. p. m., and glass wool or molybdenum disulfide is used as a die lubricant. The extruded shape is straightened by hot stretching before the metal cools below 800° F.

COLD DRAWING

Titanium wire and tubing are now being produced by cold drawing. The cold drawing of alloyed wire is difficult, and therefore wire of small diameters is not available. Unalloyed wire has been drawn to diameters of 0.005 inch, while the smallest diameter alloy wire pro-

duced is 0.04 inch. One of the biggest problems in cold-drawing wire has been in properly lubricating the dies to prevent seizing and galling. Some success has been attained by copper plating the wire used for finer draws and by anodizing the wire before drawing. Wire is used for rivets and electrical applications and as welding filler.

Superior Tube Co. produces a seamless titanium tubing by using inside-dimension mandrels and plugs. Hot, extruded billets are used as stock for the cold-drawn tubing. The tubing has a smooth surface and close tolerances.

Two companies also turn out Weldrawn tubing. An annealed, cold-rolled strip is shaped into tubing by rolls, and the seam of the tubing is fusion-welded automatically by an arc-welding machine. The welded tube is then cold-drawn the same as seamless tubing.

POWER-BRAKE FORMING

The power brake is a device for bending sheet into various forms. At room temperature commercially pure sheet can be bent around a radius equal to 2–3 times its thickness. Alloy-grade sheet can be bent around a radius of 3–5 times its thickness. To accomplish bending at room temperature, slow speeds must be employed with greater pressure required than to bend carbon steel.

When the titanium sheet and the brake dies are heated up to 500° – 800° F., sharper bends may be made, and the danger of breakage is greatly reduced.

STRETCH FORMING

Stretch forming is usually accomplished by wrapping the material around a die, meanwhile applying enough tension to the edges to insure plastic flow. This method is useful in forming double-curved parts, curved angles, and channels that have first been bent on the power brake. To prevent failure from necking, localized stresses must be avoided. The jaws or grips that hold the titanium are coated with emery paper to prevent scratching the titanium sheet and consequent localized stresses.

Stretching may be carried out at room temperature if a stretch of less than 5 percent is desired. For greater stretches, the operation must be carried out at elevated temperatures. Unalloyed titanium may be stretched more severely at 400° – 600° F., while alloyed titanium should be heated to 800° – $1,000^{\circ}$ F. Slow stretching and holding at full load for a period of time yield a more uniform product. If the metal has been heated during stretching, annealing and final stress relieving may be necessary.

DEEP DRAWING

In deep drawing a shape is formed by controlled plastic flow of a material. The material must be stressed beyond its elastic limit but not enough to cause rupture. It is especially suited for forming cup-shaped objects. Speeds to deep-draw titanium must be about one-half of those used for steel.

Trouble was encountered in deep-drawing titanium because of the tendency of the metal to gall. As the metal flows over the surface of the die, particles of titanium rub off. These particles adhere to the die surface, forming rough spots. As the die becomes rougher, the metal finally seizes and ruptures. Various lubricants have been used to prevent seizing and galling. Copper plating the blanks has helped to prevent scratching and scoring of the finished piece, although anodizing the metal has yielded better results. Bonderizing (coating the metal with phosphate) before applying a dry film lubricant has also proved helpful.

Deep drawing is usually carried out in a number of steps, and it has been found necessary to stress-relieve the titanium after each step by heating it to 1,325° F. for about 7 minutes. After the final operation the part is again stress relieved to prevent "season cracking" (cracks that develop after the part has stood for several weeks).

Brooks & Perkins, Inc., deep-draws titanium in one operation by heating both the blank and the hydroform die. It has found that the same techniques used to form magnesium may be used to form titanium.

HYDROPRESS FORMING

Hydropress forming can be done at room temperature in a number of stages, with intermediate annealing treatments at 1,100° F. between each stage; however, the best results have been obtained by using heated steel form blocks and parts. Pressures of 1,400–8,700 p. s. i. have been used, but higher pressures are preferable. Press forming may take place at about 800° F., and any wrinkles that occur in severe contours are taken out by hand working at 400°–500° F. Controlled torch heating has proved to be satisfactory for heating the material to working temperatures.

DROP-HAMMER FORMING

To obtain good results the parts and dies should be heated. The part may have to be lubricated if the metal is required to flow across the face of the die. Heat-resistant rubber dies heated to 300°–400° F. have been used, the titanium being heated to 800° F. Steel dies have also proved to be satisfactory,

as have hard-faced Kirksite with hardened-steel inserts. Wrinkles are removed by warm handwork.

PUNCH-PRESS FORMING

There has been some difficulty in forming parts on a punch press. Blanking and piercing have been no problem, but in drawing and forming a part, special slow press speeds must be used, allowances must be made for spring-back, heated dies must be employed, and adequate lubrication must be applied to the piece. One company did experimental work on this method of forming and used temperatures from room to 800° F. At 800° F. the male punch expanded and lodged in the female. Hot handwork was necessary on all the parts before they were satisfactory. In spite of this, punch-press forming may be satisfactory for large orders.

SPINNING

Spinning consists of forming sheet-metal disks into hollow shapes by pressing a tool against a rotating form. Titanium must be worked at elevated temperatures; consequently, the wooden chuck used in spinning must be protected from charring and burning, as the optimum temperature for spinning titanium is 1,000° to 1,300° F. Protection of the wooden chuck has been accomplished by first spinning an aluminum cover over the chuck and then spinning a steel cover over the aluminum. The purpose of the aluminum is to diffuse heat rapidly away from the heated area. The titanium is heated locally, as it is being spun, by a manifold and set of oxygas burners. The spinning tool, usually a hardened-steel roller, follows the flames.

FLARING

Large sizes of titanium tubing can be successfully flared, but difficulties have been experienced in flaring tubing less than ¼ inch in diameter. These difficulties have been reduced, making the flaring of smaller tubes possible. At room temperature it is difficult to obtain an increase of over 35 percent in tube diameter, although slightly greater increases have been obtained at elevated temperatures. One company recommends the use of flareless-type fittings or a compression fitting in which the collar is pressed into the tube to make a seal with the body.

DIMPLING

Dimpling is essentially the cupping of sheet metal to permit the use of rivets or screws with countersunk heads. Titanium may be dimpled on stationary or portable squeezers; it is best done if the dies and sheet are heated.

SHEARING

Titanium may be readily sheared with power shears designed for steel. The process requires about as much power as does the shearing of $\frac{1}{4}$ hard stainless steel, and the edges produced are clean and square. Irregular outlines made by rotary and nibbler shears are of about the same quality as those obtained on $\frac{1}{4}$ hard stainless steel.

CASTING AND POWDER METALLURGY

Casting and powder metallurgy are only related in that, by either process, a finished or semifinished form is produced without the necessity for costly forming or machining operations. Numerous problems remain to be solved in both processes, so that most of the parts fabricated by these methods have been made on an experimental basis. Both processes offer considerable hope of lowering the price of intricate fabricated parts, because less metal is required to form a finished part (owing to less scrap loss) than in other fabricating processes.

CASTING

The main problems in casting titanium are: (1) To avoid pickup of oxygen or nitrogen from the atmosphere; (2) to melt a large enough quantity of metal to fill the mold; (3) to avoid contamination of the molten metal by the crucible; and (4) to avoid contamination of the metal by the mold material.

To eliminate the first problem the melting crucible and the mold may be enclosed in a single tank, which usually contains a protective atmosphere of argon or helium (unless melting occurs under vacuum).

Problem 2 may be solved by enlarging the furnace and crucible capacity, but there are limitations to this, with present methods of melting.

Problem 3 has been eliminated by using skull melting. A copperlined, water-cooled crucible is used for this method; and a layer of titanium next to the crucible does not melt, thus forming essentially a titanium-lined crucible.

Carbon or graphite has been successfully used as a mold material. After molten metal has been poured into the mold it is only contaminated with carbon along the outside, and this surface layer may be easily removed. If carbon or graphite is to be the mold material, it is machined in sections into the desired contours. The mold is baked at $1,700^{\circ}$ – $1,800^{\circ}$ F. to remove residual volatile matter and then assembled by clamping the parts together with steel bolts. Some investigators report, however, that only simple shapes can be produced from graphite

molds, as the graphite cracks at the corners of the mold at reentrant angles when the titanium shrinks.

A powdered refractory, consisting of a zirconium oxide, has been developed especially for casting titanium. Good results are reported in using this material to cast small parts or thin sections; but, in casting larger parts, the heat of the large pool of molten titanium reduces the zirconium oxide, contaminating the titanium metal. To form a mold with this material, the powdered refractory is mixed with a liquid binder. This material, in the form of a slurry, is poured over a pattern and allowed to harden, forming one-half of the mold. The other half of the mold is prepared in a similar manner, and the two halves are clamped together for use. The mold is baked, followed by high-temperature firing, and specially treated to withstand titanium.

There are three major methods of getting the titanium from the crucible to the mold. These methods employ a bottom-pouring crucible, a tilting-type crucible, and centrifugal casting.

Furnaces may be divided into two categories: An induction heater around a graphite crucible and heat introduced by an arc between an electrode and the titanium charge. Carbon contamination in the first method is high. The second method uses a copper, water-cooled crucible, eliminating contamination by carbon.

BOTTOM-POUR ARC FURNACE

In this method of casting the mold is connected to the bottom of the crucible. When the titanium in the crucible has been melted, the plug in the bottom is pierced in some manner and the titanium flows into the mold. Figure 25 illustrates a bottom-pour furnace developed by the Bureau of Mines.

The principal parts of this furnace are: A water-cooled electrode holder, a consumable electrode of titanium, a water-cooled copper crucible, a water-cooled stopper, and a mold box that contains the mold.

To begin operations the furnace is sealed and evacuated to about 100 microns, then flushed several times with argon or helium. The water-cooled stopper is inserted in the bottom of the crucible, and an arc is struck. After the desired amount of metal has melted, the stopper is withdrawn and swung aside. The power is increased, causing the skull to melt through over the hole. The metal drains from the crucible into the mold.

The most serious problem in using this type of furnace is that drips which consolidate in the taphole are difficult to remove, so that the stopper may be reseated properly. If this difficulty is overcome, several castings may be made before the mold box is opened.

The crucible charge is limited by the depth of molten metal that the arc can pierce. This depth can be increased slightly by increasing the

power used for piercing, but this has its limits. Capacity can be expanded somewhat by increasing the diameter of the crucible.

TILTING-TYPE ARC FURNACE

In this type of furnace the crucible is tilted to pour the titanium into the mold. Details of one such furnace developed by the Bureau of Mines are shown in figure 26.

The melting and pouring apparatus was enclosed in a single chamber, and the melting was carried out under an inert atmosphere or under a vacuum. All casting operations were remote-controlled from outside the chamber.

A consumable electrode was used in this furnace. When an adequate quantity of metal had been melted, the electrode was raised and the crucible was tilted to pour the metal into the mold. A pilot-scale furnace used in this work was capable of pouring 15-pound castings at the rate of one per hour. A larger furnace being constructed in June 1955 was to have a ladle capacity of about 165 pounds, of which 65-90 pounds will be molten and available for casting.

The disadvantage of this type of furnace is that a large quantity of metal must be put into the crucible to produce a usable amount of melt. The advantage of the tilting furnace is that the amount of metal poured is not limited to the depth of metal that can be pierced by an arc of a given amperage.

CENTRIFUGAL CASTING

In this method of casting centrifugal force is used to get the molten metal from the crucible into the mold. The titanium is melted by an arc in a skull-type crucible. The mold is attached to the side of the crucible, and the entire apparatus is mounted so that it can be revolved. In 1 laboratory experiment the centrifuging was carried out at 300 r. p. m. with the mold 12 inches from the center of rotation. The capacity of this furnace was 3 ounces. The Wisconsin Centrifugal Casting Co. is producing castings weighing as much as 50 pounds by centrifugal casting.

The advantages of centrifugal casting are: The centrifugal force causes the mold to fill completely; more intricate parts can be cast than by other casting techniques; there is less porosity of the finished product; no gas is en-

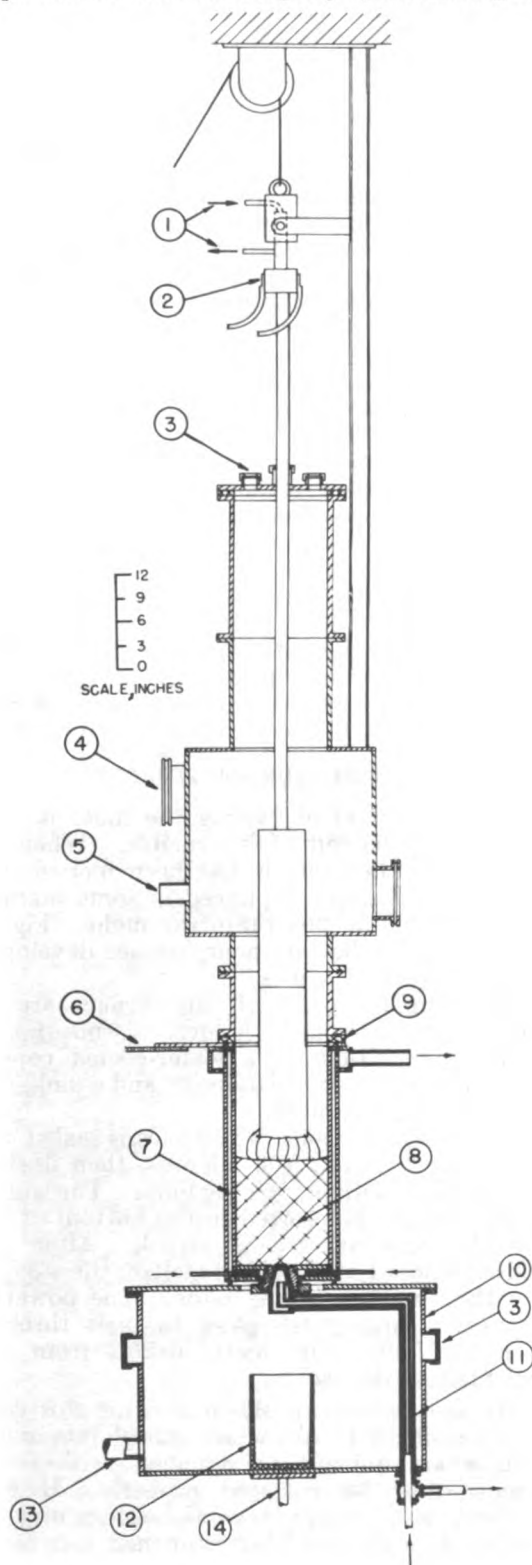


FIGURE 25.—Bottom-Pour Arc Furnace Used by Bureau of Mines for Casting Titanium.

1, Water-cooled electrode holder; 2, cathode power lead; 3, sight glass; 4, window; 5, evacuation port; 6, anode power connection; 7, water-cooled crucible; 8, molten pool; 9, insulating ring; 10, mold box; 11, stopper control rod; 12, mold; 13, evacuation port; 14, mold-box support.

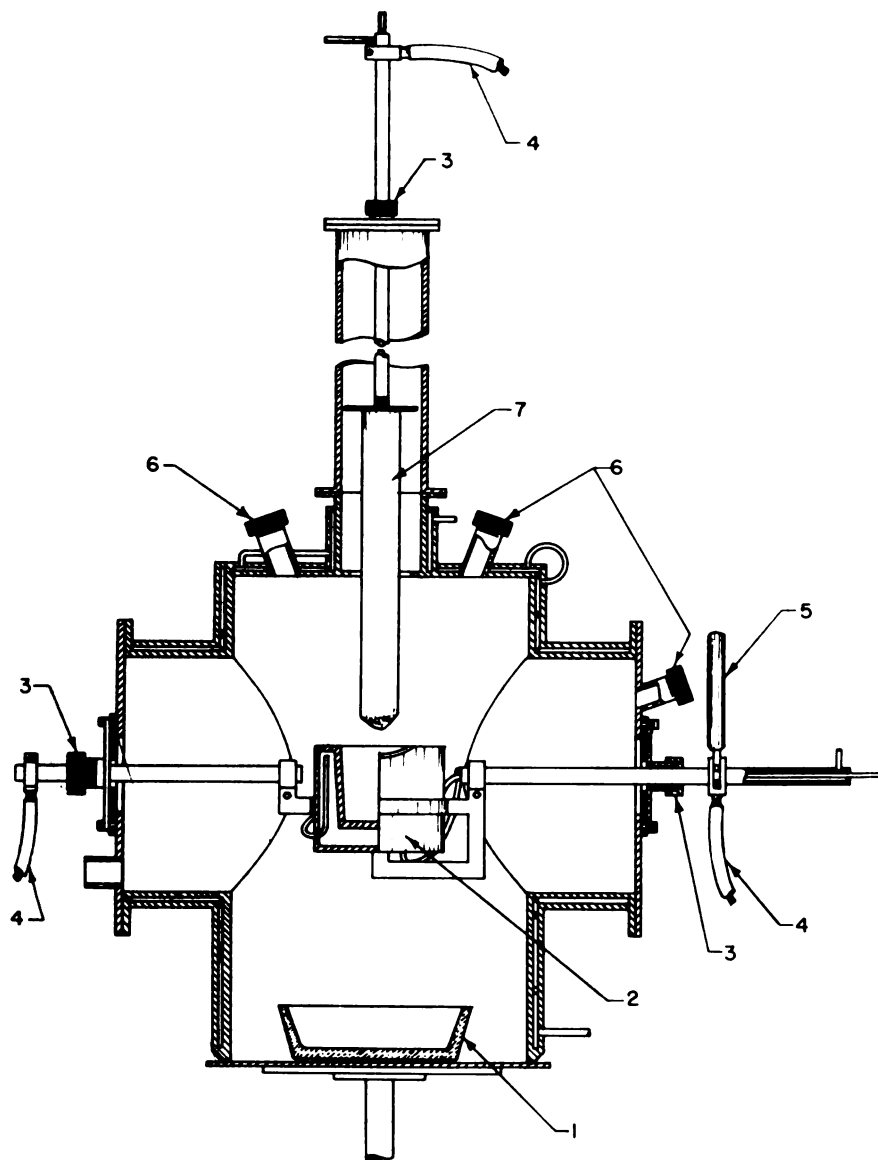


FIGURE 26.—Tilting-Type Arc Furnace Used by the Bureau of Mines for Casting Titanium.

1, Graphite mold; 2, tilting crucible; 3, "O"-ring seal; 4, power connection; 5, tilting mechanism; 6, inspection ports; 7, consumable electrode.

trapped in the mold; and the grain size of the cast metal is much finer than that produced by other casting methods.

POWDER METALLURGY

One advantage of forming titanium parts by powder-metallurgy methods is that there is very little wasted material; moreover, the density of the metal can be controlled so that parts can be produced that could not be made by any other method. Some products fabricated by this means are: Porous acid filters,

high-density ingots, shapes having cored holes, flanged sections, and symmetrical parts. Tolerances of $\pm \frac{1}{16}$ inch can be maintained.

The powder used must be low in gaseous and metallic impurities. The desired shape is formed by either hot pressing or hot forming. Hot pressing is used for large pieces and hot forming for small or medium-size pieces where production quantities are required.

In hot pressing the powder is inserted in a graphite or graphite-lined die and hot-pressed at 1,400°–2,000° F. for periods of up to 8 hours. This operation takes place in a vacuum

of 5×10^{-3} mm. of mercury. A thin, gradhite, diffusion layer forms on the titanium part, but this may be remedied by removing about 0.001–0.002 inch of the surface.

Press forming is faster than hot pressing and greater precision is attained in shape and dimension. Blanks or slugs are first pressed from the powder and sintered in a high vacuum. The blanks are then placed in tool-steel dies and formed to the shape desired in a number of forming operations. The final part need only be finish-machined.

Parts made by powder-metallurgy methods have a strength comparable to that of arc-melted titanium. Only 1.7 pounds of sponge is necessary to produce 1 pound of finished, machined part, whereas as much as 8 pounds of sponge may be required to produce 1 pound of finished part by melting, forming, and machining. More intricate parts produced by powder metallurgy may require 4.5 pounds of sponge per pound of finished part. Objects weighing as much as 125 pounds and as large as 9 inches in diameter have been turned out successfully by powder-metallurgy techniques.

MACHINING AND GRINDING

It is in the machining and grinding operations that a usable part is produced; both require special considerations in work with titanium because of the peculiar properties of that metal. A great amount of time and effort has been devoted to developing proper techniques for this phase of fabrication, but many problems remain to be solved.

MACHINING

Theoretically, titanium should machine more readily than steel because its coefficient of friction, shear strength, and unit power requirements are lower than those of steel. Furthermore, the depth of work hardening is only 0.005 inch compared with the depth of hardening (0.020 inch) for most other common metals.

In spite of these assets it is hard to machine titanium because of low tool life. This poor tool life is due mainly to the low thermal conductivity of titanium, which causes high cutting temperatures. This heat is concentrated on the cutting edge of the tool. Since the tool metal is soluble in titanium, small amounts dissolve in the titanium chip at the bearing area as the chip races over the face of the tool. If the machine is slowed or stopped suddenly, the chip will freeze or become welded to the face of the tool. When the machine is again started and the chip is knocked off the tool, a portion of the tool is carried away with the chip, dulling the tool. This action is especially disastrous in operations, such as milling, where

the tool makes only brief contact with the work.

From this it may be seen that a coolant is needed when machining titanium, and the cooling power of a cutting fluid is more important than its lubricating power. A number of cutting fluids have been used with varying success. Lard oil produced no effect. Sulfurized and chlorinated oils have some effect upon cutting properties. Carbon tetrachloride was reportedly ineffective. Some investigators reported good results using liquid CO_2 or immersing titanium in liquid baths as low as -100°F . Soluble oils have proved to be of some use.

Attention to a number of other details will also help to lengthen tool life. The tool should be rigid and the work held solidly to minimize vibration. The tool should not be allowed to ride on the work and should be disengaged from it as infrequently as possible. Tools should be kept sharpened at all times.

The composition of the tool is also important. Sintered-carbide tools are excellent from the point of "red hardness" but are brittle and tend to chip and spall. Carbides are recommended by some companies for continuous cutting, where the equipment is rigid, with reasonably rapid speeds and heavy cuts. Cast-alloy tools, such as Rexalloy and Stellite, are intermediate between carbides and high-speed steels. They can be used for slower speeds and lighter feeds, reducing the danger of edge damage by chips. High-speed steel is the most widely used tool material, and much titanium is cut with this. The best results with high-speed steel have been obtained with grades having cobalt and a high vanadium content. Slow speeds are used, but tool life is longer because of less edge damage.

TURNING

Slow speeds and heavy cuts should be used for turning titanium on a lathe. In turning forgings, a depth of cut of $\frac{3}{16}$ inch is used to get below the scale, with a slow speed of about 30 f. p. m. and a feed of 0.015 inch per revolution. After the outer layer has been removed, the speed may be increased to 150 f. p. m. (surface). A reduction in feed improves the finish produced. The best finishes are achieved at speeds of 200–300 f. p. m., with no improvement in finish above this speed but a reduction in finish below it. Finishes produced by turning titanium are better than those produced on steel.

Some turning is done dry, but better results are obtained with a coolant. Water-soluble oils seem to serve this purpose well for most turning.

The Superior Tube Co. in 1955 recommended the procedures shown in table 46 for rough-turning or finish-turning unalloyed titanium.

TABLE 46.—Optimum conditions for turning unalloyed titanium

Tool material.....	Rough-turning unalloyed titanium		Finish-turning unalloyed titanium
	High-speed steel.	Carbide..	Carbide.
Minimum feed...inch per rev.	0.040	0.015	0.008.
Speed..... f. p. m.	20-30	40-65	150-350.
Side cutting edge angle... deg	15-20	15-20	10-20.
Side rake angle..... deg	8	4	4-6
End relief angle..... deg	7-8	7-8	6.
Minimum nose radius... inch	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$.
Coolant.....	Water-soluble coolants should be used in a 10:1 ratio.		

MILLING

Welding of the chip to the milling cutter face is the major problem in milling titanium. As the tool leaves the cut, the chip freezes to the tool face and is bumped off the next time the tool enters the cut, taking off part of the tool face each time. This problem can be minimized by having the cutter take the maximum bite at the start of the cut and having the chip approach zero thickness at the exit of the cutter. This can be accomplished in slab milling by using a climb cut. Also, the work should be placed so that the cutter teeth finish the cut in a direction parallel to the feed.

The relief of the tool is critical, as a less than 10° relief leads to smearing along the flanks and a relief of greater than 15° weakens the tool. A 30°-60° corner angle on the tool or a large nose radius gives a thinner chip and minimizes chipping of the tool.

A feed of 0.003-0.008 inch per turn yields the best results. The cutting speed on titanium alloys using a carbide tool may be up to 100 f. p. m. With a cast-alloy tool the speed should not be greater than 50 f. p. m.

DRILLING

Rem-Cru Titanium Co. sets forth the rule that, in drilling titanium, one should apply the maximum force that the drill will permit. The drill should not be allowed to ride in the hole; and, if it is necessary to disengage it to clear chips from the hole, this should be done as rapidly as possible.

Breakage of the drill can be minimized by using the shortest possible drill. A jig should be used, and the holes should be designed as shallow as feasible.

Superior Tube Co. recommends a T-4 type, high-speed steel drill with a point angle of 118°, a clearance of 20°-35°, and a spiral of 20°-35°. Holes up to $\frac{1}{4}$ inch in diameter may be drilled at speeds of 12-15 f. p. m. (surface). Holes from $\frac{1}{8}$ - to $\frac{1}{2}$ -inch diameter may be drilled at speeds of 15-25 f. p. m. and feeds of 0.005-0.008 inch per revolution. The drill should be

sharpened as soon as it becomes dull to prevent it from sticking in the hole.

The Production Engineering Research Association of Great Britain has reported the following optimum conditions for drilling titanium:

1. The best drilling results were obtained with a drill having a point angle of 105° and a relief angle of 10°. Point angle and relief angles were found to markedly affect drill life.

2. A drill with 25° helix angle resulted in longer drill life than drills with 10° and 42° helix angles.

3. There is a reduction in drill life at speeds greater than 64 f. p. m. and feed rates greater than 0.0014 inch per revolution. Optimum cutting speed is 50 f. p. m. with a penetration rate of 1 inch per minute.

4. A cutting fluid should be used. Good results were obtained with a fluid containing 1 part mineral oil, 5 parts soluble oil, and 18 parts water. With this fluid drill life was 10 times greater than with sulfurized neat oil and 40 times greater than with a 1:20 soluble oil.

5. Drilling difficulties were not due to work hardening of the metal.

REAMING

Not too much difficulty is encountered in reaming holes in titanium. One company states that this can best be done with a carbide-tipped reamer with spiral flutes. Speeds of 40 to 200 f. p. m. should be used with feeds of 0.005-0.008 inch per revolution.

Rem-Cru uses a starting speed of 50 f. p. m. and a finishing speed of 100 f. p. m. A feed of about 0.008 inch per revolution is used for small holes, and 0.020 inch per revolution is used for larger holes.

TAPPING

Putting threads in titanium holes by tapping offers many problems owing to a number of factors: The galling or seizing action of titanium on the tap, the tendency of the metal to build up on the cutting edge, and the shrinking action of the tapped hole at completion of the cut.

The skip-tooth, three-flute tap is the most desirable for this operation. Rigid setups are required, and power tapping should be used. It was found that holes drilled with dull drills will result in tap breakage, so the hole must be clean. A heavy cut with low speeds and coarse feeds is recommended. Some type of cutting fluid should be used. The University of Michigan claims good results with a paste composed of a mixture of SAE30 lubricating oil and lithopone. Carbon tetrachloride was also found to be good. The Superior Tube Co. uses a chlorinated, wax-type oil for tap lubrication.

EXTERNAL THREADING

Until recently it was almost impossible to thread titanium externally using dies, and threads had to be turned or chased on a lathe.

Most of the threading problems have been solved, so that in commercial practice bolts are threaded cold in dies, the bolt being headed hot. Some companies recommend chasing the bolts with tangential chasers at 72 r. p. m.

BROACHING

Most investigators report that this is one of the most difficult machining operations to perform on titanium. However, the University of Michigan states that good performance with high-speed broaches is obtained when the correct relief angle, rake angle, and rise per tooth are used. Indications are that cutting efficiency and surface finish are improved by increasing the relief angle of the broach from a normal $\frac{1}{2}^{\circ}$ – 3° up to 5° . Broaching should be done in one pass.

Carbide-tipped broaches or broaches of high-speed steel may be used and should have a tooth load of 0.004 inch and a slow, steady speed. Sulfurized oil has served satisfactorily as a coolant.

SAWING

Power hacksawing has proved to be an effective means of cutting titanium. All titanium alloys except those high in carbon can be hacksawed at reasonable speeds. The cutting rate is about 25–50 percent slower than in cutting steel, and the blade life is 50 percent lower. The saw must not be allowed to ride on the work, as it is virtually impossible to cut titanium unless a positive feed is maintained. If the saw rides on the work, smearing occurs, and the teeth become dull. The sawing machine should be structurally rigid and free of vibrations. The work must be held securely, the blade tension should be high, and a coolant must be used. Coarse pitch blades are recommended with 2–6 teeth per inch. One rule for hacksawing titanium is slow speed and heavy feed.

In band sawing a positive feed must also be maintained, but tools fail when the feeding force approaches 100 pounds. The University of Michigan finds that, from an economical standpoint, a minimum feed rate of 40×10^{-6} inches per tooth must be maintained. On SAE steel the feeding rate is half the cutting force, whereas with titanium the feeding rate should equal or exceed the cutting force. Bandsaws and friction saws are used commercially to cut small bars and sheet.

Large sections of material have been effectively cut by using an inserted-tooth, circular saw. One operator states that there should be 0.017 inch between the high and low teeth, the rake angle should be 5° , and the speed should be 19 f. p. m. (surface).

Rem-Cru Titanium, Inc., has had good results with abrasive saw cutting. This company used a spindle speed of 1,000 r. p. m., with the cutting rate for small sections 5–6 square inches of cross section per minute. A 9-inch-diameter billet of Rem-Cru C130Am can be cut through in 15 minutes, using an abrasive saw. The company uses a 1:50 Campbelline soluble oil and water as a coolant for this type of work. About 1 sq. in. of grinding wheel is lost per 1–2 sq. in. of metal cut. This amounts to a wheel cost of around 1–2 cents per square inch of metal cut.

FLAME CUTTING

Titanium sheet has been flame-cut without too much difficulty. One worker reports that an audible "pinging" occurred during cutting. The pings were caused by cracks forming in the heat-affected zone of the flame-cut edge. The cracks were all transverse, being a maximum of $\frac{1}{16}$ inch in length and quite shallow. They were readily removed by grinding away about $\frac{1}{2}$ inch of the material. To eliminate this difficulty, the titanium was preheated by employing a preheating tip, which preceded the cutting tip.

Titanium Metals Corp. of America states that the smoothest cuts are made at the highest possible speeds with the least amount of preheating. To avoid thermal shock cracking of the cut surface, they place the cut in a furnace at 1,100° F. for 1 hour and then allow it to air-cool.

GRINDING

Grinding is "machining with a myriad of little single-point cutting tools." Each grain of the grinding wheel must remove a particle of metal; then the surface of the grain must break, exposing a fresh cutting surface. If the grain does not break rapidly enough, the surface of the wheel becomes glazed or loaded, resulting in burning or cracking of the metal. If the grain breaks too rapidly, the grinding becomes too expensive.

The grinding of titanium introduces special problems, because the high localized temperatures developed cause the titanium to combine chemically with the grinding-wheel material. Certain titanium alloys are prone to develop grinding cracks and distortion because of the notch sensitivity and low thermal conductivity of titanium and the high stresses involved.

A coolant must be used during grinding. Oil is effective, but a fire hazard results owing to the oil mist formed at high speeds and the intense sparks generated by grinding titanium. Water is no good as a coolant. Sodium nitrite is the coolant most widely recommended for this work. It is believed that the most effective

coolant is one that will inhibit the reaction between the titanium and the grinding-wheel materials.

A silicon carbide wheel can be used at speeds of 5,000–6,000 f. p. m. (surface). An aluminum oxide wheel is effective at speeds of 2,000–2,500 surface f. p. m.

JOINING

WELDING

Welding is the process of joining metals by applying heat and/or pressure. Fusion welding, which includes gas and arc welding, requires that the metals to be joined be melted at the point of jointure. Pressure welding employs heat and pressure to join the metals without melting. Gas welding is not used on titanium, but arc welding and various types of

pressure welding find extensive use in joining pieces of titanium.

FUSION WELDING

Titanium parts must be protected from atmospheric contamination if they are to be fusion-welded. This may be accomplished by enclosing the work and welding equipment in an inert, gas-filled chamber or by using some device to blanket the work with an inert gas during welding. The Bureau of Mines pioneered the welding of titanium, having begun its investigations of this problem in 1948 before titanium metal was commercially available. One result of this work was development of a collapsible rubber and steel chamber to be used for enclosing the work and welding torch. (See fig. 27.) The chamber was first collapsed to expel air and then inflated with helium



FIGURE 27. Collapsible Rubber and Steel Tank Developed by Bureau of Mines for Welding Titanium.

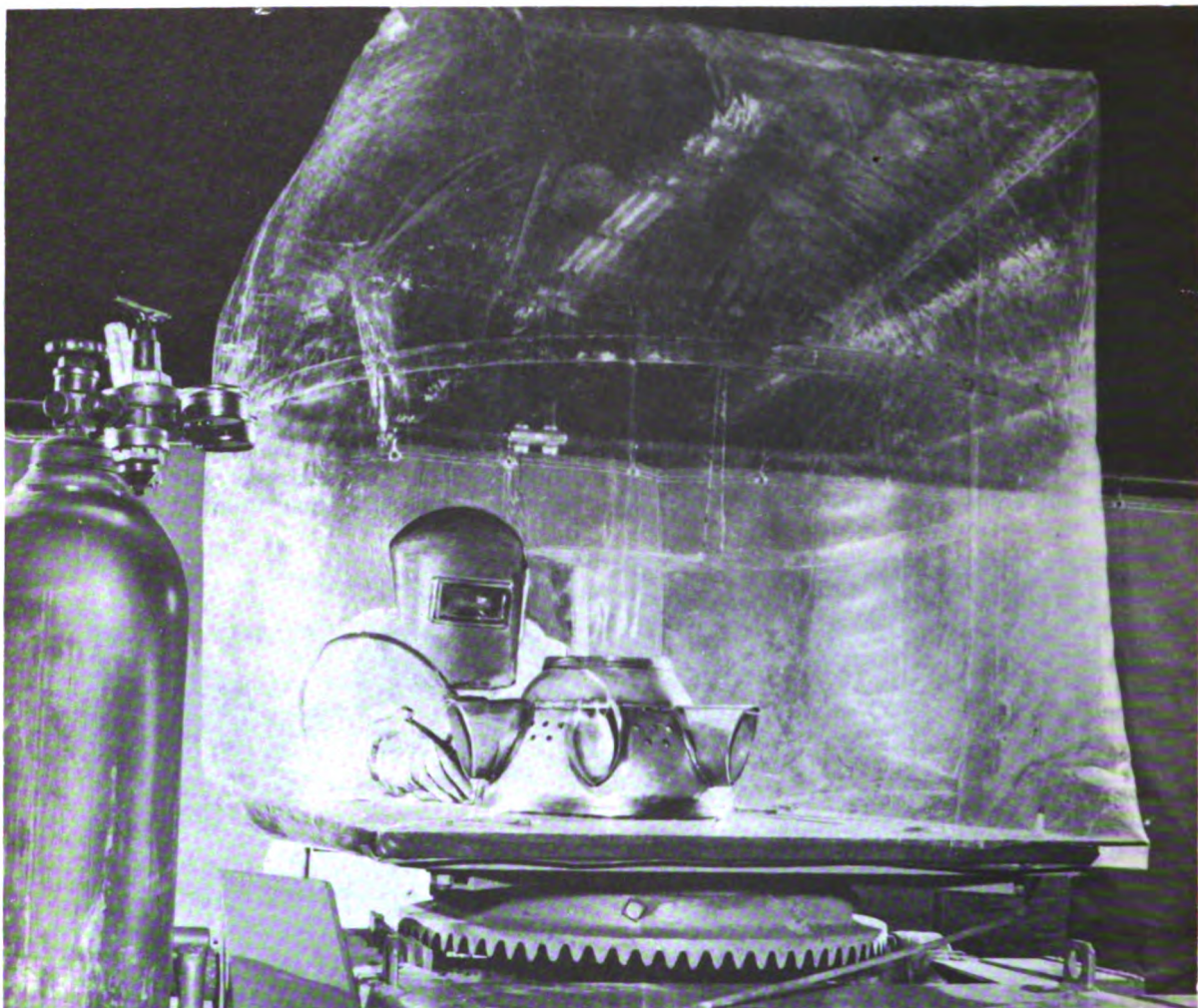


FIGURE 28. Plastic Tent Developed by Solar Aircraft Co. for Welding Titanium.

Rubber gloves were attached to the walls of the chamber to enable the operator to manipulate the work and welding torch. For welding smaller pieces the Bureau developed various boxes made of steel, with a glass aperture for viewing the work. Modifications of this equipment are used in some commercial welding operations. Solar Aircraft Co. has welded titanium in a transparent plastic bag inflated with argon. (See fig. 28.)

If a chamber is not employed to contain the inert atmosphere, special nozzles and jigs must be used to direct the flow of the inert gas on the upper surface of the piece. A tight metal backing may be used on the underside of the piece, but some prefer an inert gas. Tests have shown that if copper is the backup material, higher current settings must be used than if steel is employed for this purpose.

Either helium or argon is used as the inert gas, depending upon individual preferences. The gas must be very pure, because the presence of oxygen, nitrogen, and moist air in quantities as low as 0.25 percent may be deleterious to the ductility of the weld. Small amounts of hydrogen and dry air may be tolerated.

Atmospheric contamination in the heated zone on both sides of the weld may be reduced by using holddown bars, placed on both sides of the weld.

Arc welding may be done with or without a filler material. The filler may consist of wire or strips of the same composition as the material to be welded. If filler is used, the weld bead must be ground to produce a flush weld, and this may cause the weld to lose its ductility. Marquardt Aircraft Co. reports good results

in producing a flush weld without filler material. It recommended that argon gas be used as a backup material. The positive pressure of the gas on the underside of the weld prevents the weld from sagging while still molten.

There are two major methods of arc-welding titanium, using either a consumable or a non-consumable-electrode. In the consumable-electrode process the arc is struck between a titanium electrode (in the form of wire) and the material to be welded. The electrode serves as filler material. In the nonconsumable-electrode method the arc is struck between a tungsten electrode and the metal to be welded.

It is interesting to note that the color of the metal surrounding the weld indicates the degree of atmospheric contamination and therefore is a gage of the quality of the weld. The Marquardt Aircraft Co. has published the information on weld colors given in table 47.

TABLE 47.—*Color indications of weld ductility*

Weld-metal surface color	Bend to failure over 2T radius,°	
	No filler rod	Filler rod used
Silver.....	180+	115
Light straw.....		88
Dark straw.....		71
Light blue.....		66
Dark blue.....		21
Gray-blue to free scale.....		0

SOURCE: Levy, Alan W., and Wickham, Robert, Fusion Welding Titanium Sheet Without Filler Rod: Modern Metals, vol. 11, No. 4, May 1955, pp. 48-54.

These color indications are not foolproof, however, as there are certain conditions under which a silver color is produced and the weld is unsound. This might result if the inert-gas blanket is intermittent, so that the atmosphere will touch the surface while the weld is still molten. Oxygen may then penetrate the weld, with little resultant surface oxidation. In other instances while thick material is being welded a blue color may result from surface contamination, but atmospheric penetration has not been deep enough to affect the quality of the weld.

In most instances the weld formed by fusion welding of commercially pure titanium is comparable in strength and ductility to the parent metal. The A. O. Smith Co. made welding tests on five types of alloys containing chromium, iron, manganese, aluminum, and molybdenum. The material to be welded consisted of $\frac{1}{8}$ - to $\frac{1}{4}$ -inch plates, and a filler material of the parent alloy was used with a tungsten arc.

Alloys with chromium, iron, and manganese were satisfactorily welded. Welds of titanium-manganese-aluminum alloys (4 percent manganese, 4 percent aluminum) were subject to transverse cracking. Titanium-chromium-molybdenum alloy (4 percent chromium, 2 percent molybdenum) welds had good characteristics. The ductility of some of the welds was improved by postwelding heat treatment.

Many investigators consider it unsafe to weld any alloy containing a beta stabilizing element. The initial weld may be sound, but after it has aged it may become brittle and fail. A special weldable alloy, containing only alpha stabilizing elements (5 percent aluminum, 2.5 percent tin), was available in 1955.

Fusion-welding titanium to dissimilar metals has had very limited success.

PRESSURE WELDING

This type of welding includes resistance welding and true pressure welding in which high pressure is the main welding agency.

Resistance welding includes spot, seam, and flash welding. The heat necessary for the weld is supplied by resistance of the metal to an electric current. In spot welding the heat and pressure are restricted to a small area, while seam welding consists essentially of a string of overlapping spot welds. Flash welding obtains its heat from an arc established between the two pieces to be welded, and pressure is applied when the proper temperature has been reached.

Titanium can be seam- and spot-welded at a variety of machine settings. The tensile and shear strength of the welded material is good, but the ductility is lowered somewhat. Because of the rapidity of the heating and cooling of the area welded, the weld need not be protected by an inert atmosphere. Single-phase a.-c. equipment has been used for spot welding, employing a current setting of 6,000-12,000 amperes and a force of 400-1,200 pounds for about 15 cycles. Electrode configuration does not have a marked influence on weld properties. No surface treatment is necessary before resistance-welding titanium with a mill finish or a light oxidation coating. For heavier oxide coats, the metal should be descaled, using a 48-percent nitric, 2-percent hydrofluoric acid solution at 70°-90° F. Resistance welding of titanium to other metals has been unsuccessful.

Flash welding seems to be a promising method of producing very good welds in titanium. The heat and pressure required to make the weld cause a bulge that must be removed by hammering while the weld is hot. Because of this forging action, a more ductile structure is produced than in arc welding, and an inherent grain refinement results. Flash welding is best

accomplished in a machine with rapid pickup and burnoff to prevent oxidation and may be done either with or without a protective inert atmosphere covering the work.

Good results have been obtained in true pressure welding of titanium, either with or without heat. The amount of pressure required to produce a good bond depends upon the size and shape of the material. The metal must be fairly ductile, because an 85-percent deformation occurs in the process. Heat may be supplied by induction heating or by an oxyacetylene torch at temperatures not in excess of 2,200° F. Successful welds have been made between titanium and copper and titanium and steel.

BRAZING

Brazing is a joining process in which the filler material has a melting point lower than the metal to be joined, provided that the filler material has a melting point greater than 800° F. This is differentiated from soldering, in which the filler has a melting point lower than 800° F.

Silver or silver compounds have proved to be the best filler materials for brazing titanium, although aluminum has yielded fair results. Silver has good spreading power without excessive erosion or undercutting of the titanium, owing to the low solubility of titanium in molten silver.

The parts to be brazed may be heated by an oxyacetylene torch, electrical resistance heating, or heating in an inert-gas-atmosphere furnace. Good results have been reported in using a commercial fluoride flux, as the flux protects the titanium from atmospheric contamination during brazing and assists the flow of brazing compound by removing metallic films on the surface. However, North American Aviation does not use a flux for its brazing work. The joint should be made quickly without excessive or prolonged heating. A dry inert gas should be used to protect the heated area.

No difficulties have been experienced in brazing titanium to titanium. Titanium has been successfully brazed to aluminum by first coating the titanium by dipping it in a molten bath of aluminum. Stainless steel has been joined to titanium by pre brazing the steel with the brazing alloy.

A vacuum-brazing technique was developed in 1955 to produce honeycomb sandwich sections of titanium. The sandwich is assembled with shim strips of brazing alloy (silver or silver-manganese) separating the titanium honeycomb from the two titanium facing sheets. After being placed in a retort, the sandwich is weighted to assure positive contact of all the parts during the brazing process. The retort is placed in a vacuum furnace where actual brazing takes place. Temperatures employed are lower than those normally used for brazing and no fluxes are needed. After brazing, the section is trimmed to final size.

SOLDERING

Titanium can be readily soldered if a thin film of silver, copper, or tin is first deposited on the surface. This is accomplished by fusing a metal-depositing flux (usually a chloride salt) on the surface. The molten solder can then be flowed onto the deposited film by heating it with a soldering iron, using commercial soldering fluxes.

RIVETING

Titanium may be riveted with stainless steel, Monel, high-strength aluminum, and titanium rivets. Aluminum rivets are not recommended, though, because of the galvanic corrosion that occurs when aluminum is coupled with titanium. If titanium rivets are used, special techniques must be employed. With standard riveting equipment, cold riveting with titanium rivets has not been very successful, as the rivets do not swell to fill the holes. Greater pressures and slower rates must be used with titanium rivets than with most other types of rivets. Results were good using pressures of 0 to 5,000 pounds exerted over a period of 1 second. One-eighth-inch buttonhead rivets were successfully driven at 5,100 pounds pressure by first annealing them for 20 minutes at 1,300° F. In one experiment 1/8-inch rivets were inserted in drilled sheets, and the rivet was spread by placing it in a spot welder.

To prevent galling of cold-headed titanium rivets, the rivets may be copper-coated or anodized.

7. STRUCTURE OF THE INDUSTRY .

GENERAL

The titanium industry is characterized by a moderate degree of vertical integration from minerals to finished product. For example, E. I. du Pont de Nemours & Co., Inc., engages in mining operations and produces pigments, titanium tetrachloride, and titanium sponge. The National Lead Co., through various divisions and subsidiaries, produces rutile and ilmenite ores, titanium pigments, ferrotitanium, and titanium chemicals and compounds. With Allegheny Ludlum Steel Corp. it is a coowner of Titanium Metals Corp. of America, which manufactures its own titanium tetrachloride, reduces this to titanium sponge, melts the sponge, then turns out titanium mill products.

Another important characteristic of the industry, particularly the primary-metal branch, is the merging of companies in pairs. Although the reasons for merging may not be the same, the partners usually supplement each other in an important area of research, production, or marketing. The Titanium Metals Corp. of America results from a joint venture by the National Lead Co. and Allegheny Ludlum Steel Corp. National Lead's interest stems from its Titanium Division and its Titanium-Alloy Manufacturing Division (created after the absorption in 1948 of the Titanium Alloy Manufacturing Co.), which mine ilmenite and rutile ore and produce pigments, alloys, and chemicals. Allegheny Ludlum is a leading fabricator of stainless steel.

Rem-Cru Titanium, Inc., results from a merger of assets by Remington Arms, which is partly owned by Du Pont, and Crucible Steel Co., which produces alloy, stainless, and tool steels.

The P. R. Mallory Co. had an interest in developing and producing titanium metal and titanium alloys. Sharon Steel Co. had steel facilities that could be adapted to fabricating titanium, hence the joint effort in the form of Mallory-Sharon Titanium Corp.

The Kennecott Copper Corp. is experienced in mining, smelting, refining, and fabricating copper. New Jersey Zinc Co., with a similar background in the zinc industry, entered into a joint enterprise with Kennecott to form the Quebec Iron & Titanium Corp., which produces titaniferous slag and pig iron.

National Research Corp. and Monsanto Chemical Co. joined forces to develop new methods for producing titanium.

ORE PRODUCERS AND DEALERS

HISTORY OF DOMESTIC MINING INDUSTRY

Within the past 15 years the United States has become the world's largest producer and user of ilmenite. Therefore, the exploration, development, and expansion of domestic ilmenite-mining properties have proceeded at a rapid pace during this period of time.

From 1903 until 1917 the American Rutile Co. at Roseland, Nelson County, Va., was the only producer of titanium minerals in the United States. Before 1903 a few hundred pounds of rutile per year had been picked up in the fields of Chester County, Pa., for use in artificial teeth and as collectors' items. In 1917 Buckman & Pritchard, Inc. (a subsidiary of the National Lead Co. after 1922), began mining a sand deposit near Jacksonville, Fla. Buckman & Pritchard, Inc., produced ilmenite and rutile intermittently until 1929, when its operations ceased. The American Rutile Co., a subsidiary of the Metal & Thermit Corp., was a steady producer of rutile from its Roseland, Va., property until 1949, when rising mining costs and a lower grade of ore caused it to cease operations.

The Titanium Corp. of America first reported ilmenite and rutile production from its lode deposit at Malvern, Hot Springs County, Ark., in 1932. Rutile, brookite, and ilmenite were shipped from this mine in varying amounts from 1932 until 1944. In 1942 the Titanium Corp. of America sold this property to the Titanium Alloy Co. of Arkansas, Inc., a subsidiary of the Titanium Alloy Manufacturing Co. The property was again sold in 1943 to the Magnet Cove Rutile Co., but mining ceased in 1944.

Southern Minerals Products Corp., a subsidiary of the Vanadium Corp. of America, began mining operations in Amherst County, Va., in 1929, closed in 1931, and resumed in 1933. This property, at Piney River, Va., produced ilmenite steadily from 1933 until 1955. The property was sold to the Virginia Chemical Corp. in 1943, which in turn sold it to the Calco

Chemical Division of American Cyanamid Co. in 1945.

About 1939 the Riz Mineral Co. began recovering ilmenite and rutile from sands at Vero Beach, near Melbourne, Fla. The company continued to operate the property under this name until 1948, when the name was changed to the Florida Ore Processing Co., Inc. This company was still producing in 1955.

In 1942 the Yadkin Valley Ilmenite Co., a subsidiary of the Glidden Co., began mining ilmenite from a lode-type deposit at Finley, Cladwell County, N. C. Production from this property ceased in 1952.

The Titanium Division of the National Lead Co. announced its first output of ilmenite from its deposit at Tahawus, N. Y., in 1942. This deposit has been the major domestic producer of ilmenite from its inception until 1955. (See Chapter 13, Development of New Sources of Ore, p. 151, for the history of the development of this deposit.)

The Rutile Mining Co. of Florida, a subsidiary of the Titanium Alloy Manufacturing Co. (which later became a division of National Lead Co.), began to produce ilmenite and rutile in 1943 from a deposit near Jacksonville, Fla. The Humphreys Gold Corp. operated the mine under lease from the Rutile Mining Co. and moved its entire concentration plant and equipment from Coos County, Oreg., where it had been mining chromite, to Florida.

The later entrants in the titanium-mineral-mining industry have been: E. I. du Pont de Nemours & Co., Inc., which began mining at Starke, Fla., in 1949; Baumhoff-Marshall Co. and Idaho-Canadian Dredging Co. at Cascade, Idaho, which began operations in 1951; Warren Dredging Co. at Cascade, Idaho, which started in 1952; and the National Lead Co., Jacksonville, Fla., which commenced in 1953.

DOMESTIC PRODUCERS

Ilmenite was produced in 1954 by the following companies:

American Cyanamid Co.	Piney River, Va.
Baumhoff-Marshall, Inc.	Boise, Idaho.
E. I. du Pont de Nemours & Co., Inc.	Starke, Fla.
Florida Ore Processing Co.	Melbourne, Fla.
Grimes Creek Dredging Co.	Grimes Creek, Idaho.
Hobart Brothers Co.	Winter Beach, Fla.
Idaho-Canadian Dredging Co.	Boise, Idaho.
National Lead Co.	Tahawus, N. Y.
Rutile Mining Co. of Florida	Jacksonville, Fla.
Titanium Alloy Manufacturing Division, National Lead Co.	Do.

Rutile was produced in 1954 by the following companies:

Florida Ore Processing Co.	Melbourne, Fla.
Hobart Brothers Co.	Winter Beach, Fla.
Rutile Mining Co. of Florida	Jacksonville, Fla.
Titanium Alloy Manufacturing Division, National Lead Co.	Do.

All of the companies mentioned above produced titanium minerals from sand deposits, except for the National Lead Co. operation at Tahawus, N. Y., and the American Cyanamid Co. operation at Piney River, Va. For the geographic distribution of these companies, see figure 30 (p. 108).

In 1955 E. I. du Pont de Nemours & Co., Inc., began mining a sand deposit at Lawtey, Fla., and Marine Minerals (a Crane Co. subsidiary) began dredging sands near Aiken, S. C.

Humphreys Gold Corp. does the actual mining for both Du Pont and National Lead on their Florida properties. Hobart Bros. Co. was the only welding-rod producer that mined titanium minerals in 1954. Concentrate from the Hobart Bros. mines was separated in the plant of the Florida Ore Processing Co., Melbourne, Fla. In 1955 the company began to build its own mill.

FOREIGN SUBSIDIARIES

In 1915 five American companies were mining titanium minerals in other countries through subsidiaries. These include Kennecott Copper Corp. and New Jersey Zinc Co. (Quebec Iron & Titanium Corp., Canada); International Titanium Corp. (Metal Recoveries Pty., Ltd., Australia); National Lead Co. (Titan Co., A/S, Norway); Titanium Alloy Manufacturing Co. Pty., Ltd., and Mineral Deposits Pty., Ltd., Australia); and Yuba Consolidated Gold Fields (Portuguese-American Tin Co., Portugal). The International Titanium Corp. is jointly owned by Ventures, Ltd., of Canada and Metal & Thermit Corp., an American ferrotitanium producer.

Quebec Iron & Titanium Corp. produced a titaniferous slag from an ilmenite-hematite deposit at Allard Lake, Quebec. Metal Recoveries Pty., Ltd., mined Australian beach sands, as did Titanium Alloy Manufacturing Co. Pty., Ltd. Portuguese-American Tin Co. dredged sands in northern Portugal. Titan Co., A/S, mined titaniferous iron ore in Norway.

In 1954 the Republic Steel Corp., Cleveland, Ohio, announced acquisition of a tract of land 6 miles long and 1½ miles wide at Oaxaca, Mexico, containing rutile in a lode-type deposit, with a reserve estimated by the company at 25 million tons of rutile.

DEALERS

A number of companies buy and sell titanium minerals, usually importing their ores from overseas. The chief source of the ilmenite that they sell is India, and the chief source of rutile is Australia, although some of them also deal in domestically produced minerals and titanium slag. Their customers are the smaller

consumers of titanium minerals, as the larger consumers have their own mines or buy their own ore to supply their needs. A list of the dealers and their addresses follows:

Ilmenite dealers—1954

Berkshire Chemicals, Inc., 420 Lexington Avenue, New York 17, N. Y. C. Tennant Sons & Co. of New York, 100 Park Ave., New York 17, N. Y.	Foote Mineral Co., 18 West Cheltenham Ave., Philadelphia 44, Pa.
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Rutile dealers—1954

Berkshire Chemicals, Inc., 420 Lexington Ave., New York 17, N. Y. International Titanium Corp., 100 East 42d St., New York 17, N. Y. Oretraction, Inc., 7425 Thomas St., Pittsburgh 8, Pa. Foote Mineral Co., 18 West Cheltenham Ave., Philadelphia 44, Pa. Metallurg, Inc., 99 Park Ave., New York 16, N. Y. Metal Traders, Inc., 67 Wall St., New York 5, N. Y.	Ceramic Color & Chemical Manufacturing Corp., 13th St. and Blockhouse Run, New Brighton, Pa. Phillip Bros., Inc., 70 Pine St., New York 5, N. Y. National Lead Co., Titanium Alloy Manufac- turing Division, Box C, Bridge Station, Niagara Falls, N. Y. C. Tennant Sons & Co. of New York, 100 Park Ave., New York 17, N. Y.
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TETRACHLORIDE PRODUCERS

All of the producers of primary metal in early 1955 also manufactured all or part of their own titanium tetrachloride. E. I. du Pont de Nemours & Co., Inc., at its Edge Moor, Del., plant made tetrachloride from a mixed product of ilmenite, rutile, and leucoxene for use at its Newport, Del., sponge facilities. Chlorination units for the other sponge producers used rutile and were located at the metal plants of the following companies: Dow Chemical Co., Midland, Mich.; Cramet Inc., Chattanooga, Tenn.; and Titanium Metals Corp. of America, Henderson, Nev. In addition, Cramet, Inc., received titanium tetrachloride from both Dow Chemical Co. and the Stauffer Chemical Co., Lewiston, N. Y.

The Ashtabula, Ohio, plant of the Electro Metallurgical Co., which was to begin operations in 1956, will use titanium tetrachloride from the Columbia Southern Chemical Corp., which will complete construction of a plant at Natrium, W. Va., in 1956. Electro Metallurgical Co. will purchase the rutile, which will be processed into titanium tetrachloride by the Columbia Southern Chemical Corp.

SPONGE PRODUCERS

UNITED STATES

The Bureau of Mines work outlined in chapter 5 stimulated the interest of industry in titanium. A pilot plant for producing titanium sponge was constructed by Du Pont at Newport, Del., in 1948. The pilot plant was expanded through successive stages, until by 1952 Du Pont was producing 2½ short tons of titanium sponge per day. Government aid, in the form of a contract with the Defense Materials Procurement Administration (DMPA), encouraged the program, which expanded Du Pont's capacity to 3,600 short tons per year by mid-1954.

The National Lead Co. was another early entrant into the new field. Pilot plants were constructed at Sayreville, N. J., in 1949 and at Niagara Falls, N. Y., in 1951. National Lead operated the Bureau of Mines pilot plant from November 1950 to November 1951 to familiarize its personnel with the new techniques involved.

Early in 1950 National Lead Co. and Allegheny Ludlum Steel Corp. organized the Titanium Metals Corp. of America. Allegheny Ludlum Steel Corp. had established its position in titanium in 1949, when it put a semicommercial titanium-melting facility in operation. TMCA leased portions of a Government-built magnesium plant at Henderson, Nev., and began operation in September 1951. The company signed a contract with DMPA in 1951, which set a goal of 3,600 short tons of titanium sponge per year by the middle of 1953; however, this goal was not met until 1954.

After a number of years of operating a pilot plant at Chicago, Ill., the Crane Co., through its subsidiary, Cramet, Inc., signed a contract with the Government in 1953 for constructing a titanium-sponge plant at Chattanooga, Tenn. This plant, with a rated capacity of 6,000 tons per year, went into production in the latter half of 1954 and sold its first sponge to the Government in the spring of 1955. Some of the titanium ore for the operation will be supplied by a subsidiary (Marine Minerals, Inc.) from a deposit near Aiken, S. C.

Dow Chemical Co. experimented for several years with electrolytic processes for producing titanium and also operated a pilot plant utilizing the Kroll process. In early 1954 this pilot plant was reportedly capable of producing 600 pounds of metal daily, and in July 1954 a contract was signed with the General Services Administration to expand the capacity to 1,800 tons per year by January 1956.

Electro Metallurgical Co. Division of Union Carbide & Carbon Corp. also signed a Government contract in 1954 for erecting a titanium-

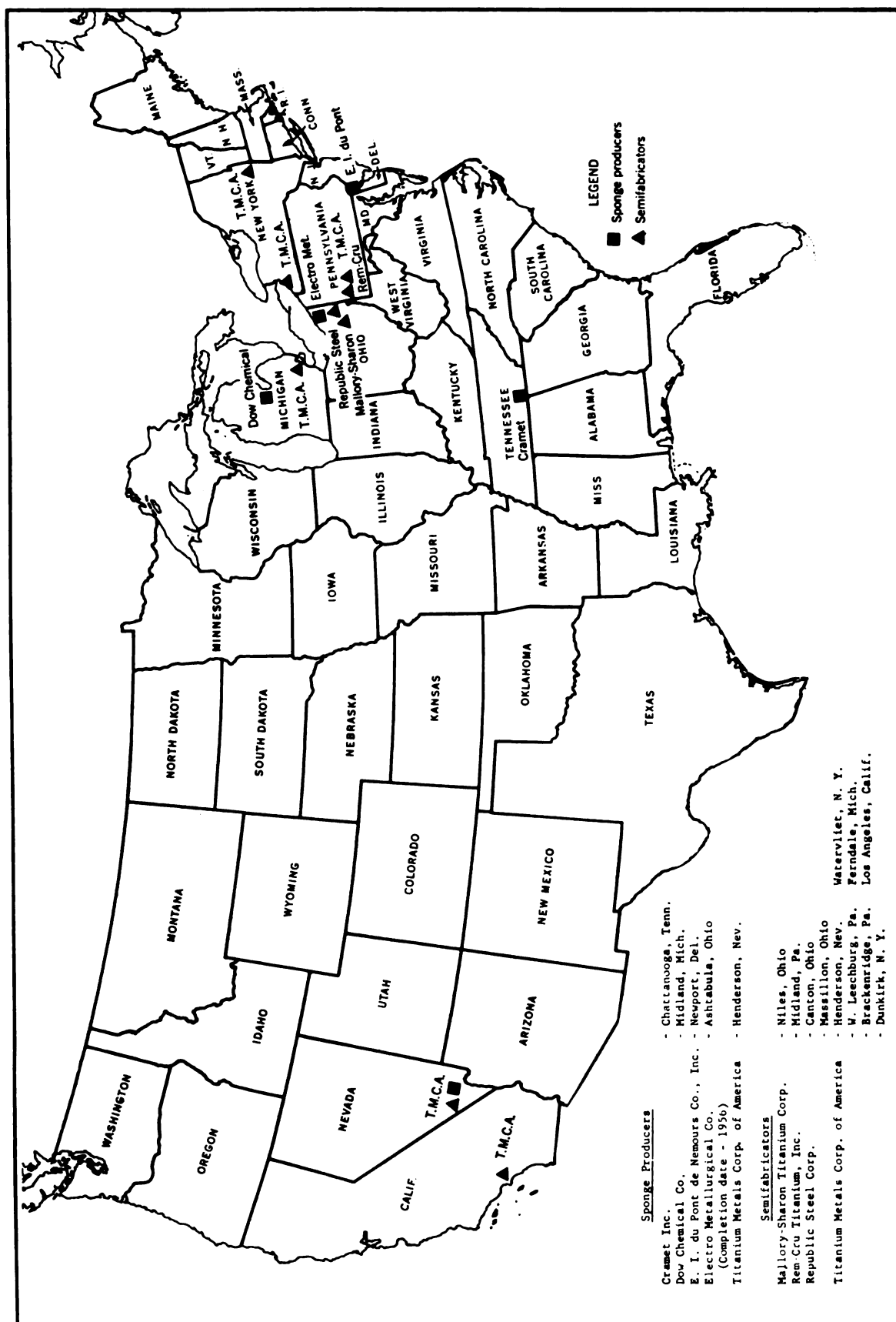


FIGURE 29. Geographic Location of Titanium-Sponge Producers and Semifabricators in the United States, 1955.

metal plant at Ashtabula, Ohio. The plant, which will have a capacity of 7,500 tons of sponge a year, will produce metal by a sodium-reduction method and active operation was planned for 1956.

Other companies, which may go into commercial production because they were operating or constructing pilot plants in 1955, are: Kennecott Copper Corp. (pilot plant at Battelle Memorial Institute); Western Pyromet Co., Manteca, Calif.; The Glidden Co., Baltimore, Md.; Horizons, Inc., Stamford, Conn.; National Research Corp. and Monsanto Chemical Co., Cambridge, Mass.; and the Wah Chang Corp. (cooperating with the Bureau of Mines at Boulder City, Nev.).

Commercially pure titanium sponge produced in 1954 included material from E. I. du Pont de Nemours & Co., Inc., Newport, Del.; Titanium Metals Corp. of America, Henderson, Nev.; Dow Chemical Co., Midland, Mich.; Cramet, Inc., Chattanooga, Tenn.; and the Federal Bureau of Mines, Boulder City, Nev. Production of titanium sponge by the Bureau of Mines under DMPA contract DMP-76 ceased September 7, 1954, about 2 months before the contract's termination date (October 31, 1954). Bureau of Mines production of acceptable titanium sponge metal under the contract totaled 246 tons. Figure 29 shows the geographic location of commercial sponge facilities in 1955.

The only company reporting production of high-purity titanium by the iodide process in 1954 was the Foote Mineral Co., Philadelphia, Pa. High-purity titanium has been produced in some previous years by Battelle Memorial Institute, Columbus, Ohio, and New Jersey Zinc Co., Palmerton, Pa.

Metal Hydrides, Inc., Beverly, Mass., manufactured titanium metal powder and titanium hydride powder in 1954 by the reduction of titanium dioxide with calcium hydride. Another producer of powder was the Chicago Development Corp., Riverdale, Md.

CANADA

In Canada a new electrolytic process was studied on a pilot-plant scale by the Shawinigan Water & Power Co. in 1954. The company reported that its process would produce titanium metal at prices substantially lower than was possible in 1954 commercial operations. Experimental work on the production of ductile titanium metal was also being conducted by Dominion Magnesium, Ltd. In 1954 this company produced titanium metal with a purity of 96 to 98 percent.

FRANCE

France had two pilot-plant operations in 1954. The Ingenieur à la Société d'Électrochimie

d'Électrometallurgie et des Acières Électrique d'Ugine had a plant at Lex Clavaux (South France) where it made about 2 tons of sponge per month. The other company, Pechiney, Compagnie de Produits Chimiques et Électrometallurgiques operated a plant at Saint Jean de Maurienne.

GERMANY

Kroll's experimentation with the magnesium-reduction process in Germany until 1939 resulted in its adoption by Degussa and Osram, two large German manufacturing firms. Degussa produced titanium in its Frankfurt am Main plant from 1938 to 1942, reaching a maximum yearly output of 1,050 pounds in 1941. The Osram plant turned out approximately 65 pounds per month from 1942 to 1944. Osram has not reported any production since World War II, but Degussa was again operating a pilot plant at Frankfurt am Main in 1955. Tiangesellschaft, a subsidiary of the National Lead Co., had a pilot plant at Leverkusen, Germany, which had a capacity of 2.2 short tons per month in 1954.

JAPAN

The chief foreign producer of sponge in 1954 was Japan, where three companies produced metal for export. The Osaka Titanium Co., Ltd., Amagasaki, began production in 1952, followed by the Nippon Soda Co., Ltd., Takaoka, in 1953, and the Toho Titanium Co., Ltd., Chigasaki, in 1954. Two other companies made titanium on a pilot-plant scale in 1954: The Nippon Denki Yakin K. K. (Japan Electric Metallurgy Co., Ltd.), Higashi, Kanagawa; and the Mitsui Kozan Kogyo K. K. (Mitsui Metal Mining Industry Co., Ltd.), Hibi.

UNITED KINGDOM

In the United Kingdom, Imperial Chemical Industries, Ltd., in 1954 was constructing a 1,500-ton-per-year sponge plant at Wilton, England, that was scheduled to be completed sometime in 1955. The Fullmer Institute was also experimenting with various processes for producing titanium metal.

SEMIFABRICATORS

UNITED STATES

In 1955 four companies were melting titanium sponge on a commercial scale. These same companies produced and sold mill products, such as sheet, plate, bar, wire, and forging billets. A fifth company, Harvey Machine Co. of Torrance, Calif., melted sponge and cast

forging and extrusion billets on a semicommercial scale for use in its fabricating facilities. Mill products from the other manufacturers were sold to various fabricators, who turned them into finished products.

The four commercial semifabricators and the location of their plants in 1955 were as follows (see also fig. 29):

Company:	Plant location
Mallory-Sharon Titanium Corp.	Niles, Ohio.
Republic Steel Corp.	Canton, Ohio. Massillon, Ohio.
Rem-Cru Titanium, Inc.	Midland, Pa.
Titanium Metals Corp. of America.	Henderson, Nev. West Leechburg, Pa. Brackenridge, Pa. Watervliet, N. Y. Dunkirk, N. Y. Los Angeles, Calif. Ferndale, Mich.

Mallory-Sharon Titanium Corp. melted sponge and produced bar and rod in its Niles, Ohio, plant. It sent bars to the Sharon Steel plant at Sharon, Pa., to be rolled into sheet and plate. Republic Steel melted sponge at its Canton, Ohio, plant and had rolling facilities at Massillon, Ohio. Rem-Cru Titanium, Inc., had melting furnaces at Midland, Pa., but sent its ingots to various crucible steel mills for semifabrication. TMCA had melting facilities at Henderson, Nev., and produced strip at West Leechburg, Pa.; sheet and plate at Brackenridge, Pa.; bar and wire at Watervliet and Dunkirk, N. Y.; billets, shapes, and tube at Watervliet, N. Y.; and forgings at Ferndale, Mich., Watervliet, N. Y., and Los Angeles, Calif.

TMCA processed metal from its own sponge-producing plant at Henderson, Nev., while the other three semifabricators melted sponge, which they purchased from other producers. The processing plants of TMCA, except for facilities at Henderson, Nev., are owned by Allegheny Ludlum Steel Corp., which has a 50-percent interest in TMCA.

FRANCE

In France the two companies that produced sponge on a pilot-plant scale in 1954 also melted the sponge to form mill products on a small scale. These companies are: Pechiney and Ingenieur à la Société d'Électrochimie d'Électrometallurgie et des Aciéries Électrique d'Ugine.

GERMANY

In early 1955 two German firms were melting titanium on a small scale, Degussa at Hanau and Vereinigte deutsche Metallwerke, A. G., at Frankfurt. The ingots produced were rolled and fabricated by the firms of Friedrich Krupp and Siemens & Halske.

JAPAN

The Japanese have shown interest in melting their own sponge to produce mill products, which would then be exported. In 1954 three firms in Japan had some melting facilities. They are: Kobe Seiko-Sho K. K. (Kobe Steel Mill, Ltd.), Kobe; Sumitomo Kinzoku Kogyo K. K. (Sumitomo Metal Industry Co.) in its Nagoya copper-rolling mill; and Furukawa Denki Kogyo K. K. (Furukawa Electric Industry Co., Ltd.) in its Nikko electric copper refinery.

SWEDEN

Sweden imported a small amount of sponge in 1954, which was melted by Nynas Petroleum AB, Nynashamn; the ingot was sent to Avesta Jernverk AB, Avesta, for fabrication into sheet.

UNITED KINGDOM

The Imperial Chemical Industries, Ltd., at its Witton (Birmingham) plant has been melting sponge which it imported mainly from Japan. In 1955 ICI was expanding these facilities to accommodate sponge produced by its Witton plant which was under construction. Jessop & Sons, Ltd., Brightside works, Brightside, England, melted sponge and manufactured mill products on a pilot-plant scale. In late 1954 it was announced that Jessop & Sons, Ltd., and another British firm had bought furnace designs and operating techniques from the Titanium Metals Corp. of America.

PIGMENT PRODUCERS

HISTORY OF PIGMENT INDUSTRY

Extensive commercial production of titanium ultimately resulted from the development of ore deposits for producing titanium dioxide pigments. In 1916 the Titanium Pigment Co. incorporated the results of its pigments research in a plant for producing titanium dioxide pigments at Niagara Falls, N. Y. The Titan Co. A/S commenced operations simultaneously at Fredrikstad, Norway. By 1930 the National Lead Co. had purchased a controlling interest in these companies.

In Germany an agreement between National Lead and I. G. Farbenindustrie, A. G., resulted in the organization of Titangesellschaft m. b. H., which built a titanium-pigment plant at Leverkusen in 1928. This plant was acquired by National Lead in 1952. A similar agreement in 1933 with Imperial Chemical Industries, Ltd., created British Titan Products Co., Ltd., which constructed a plant at Billingham, England. Canadian, Japanese, and French affiliates were also added to this group. Each of

the companies had a capital tieup with National Lead, was licensed to use patents controlled by the parent company, and was assigned a marketing territory in some part of the world.

The Titanium Pigment Co. thus acquired the North American market (until this was disturbed by the entry of other American firms), British Titan controlled the market throughout the British Commonwealth and Empire (except Canada), and Titangesellschaft was allotted the balance of the market in Europe and Asia. An agreement in 1920, renewed at frequent intervals as new firms entered the cartel, provided that each new company was to be given certain territory in which it would have the exclusive right to manufacture and sell titanium pigments and compounds free from any exports into the territory by the National Lead Co. Detailed provision was made for exchange of copies of applications for patents filed by the parties to the agreement or their licensees and for filing and paying expenses incidental to the prosecution of such applications and maintenance of patents outside the territory of each. It was agreed that no party would ever question or contest the validity of any patent under which it was licensed.

A second group of titanium-pigment companies emerged during the 30's. These were also associated by patent-licensing agreements of this type. Some ties of stock ownership were discernible within the second group, whose members made mutual agreements regarding marketing territories and the exploitation of patents. This group included the Société de Produits Chimiques des Terres Rares and the Fabrique de Produits Chimiques de Thann et Mulhouse, which acquired the market and patent rights in France and its colonies; Verein für chemische und metallurgische Produktion in Germany; S. A. Titanium (Montecatini) in Italy; and Commercial Pigments Co. in the United States.

Commercial Pigments operated a plant at Baltimore, Md., which was soon taken over by the Krebs Pigment & Color Corp. Krebs was absorbed by Du Pont in 1943. In that year the American market was shared by Du Pont and National Lead in these proportions:

	Extended pigments (percent)	Pure titanium dioxide (percent)
Du Pont.....	23.5	45.1
National Lead.....	76.5	46.6
Total.....	100.0	91.7

SOURCE: District Court of the United States for the Southern District of New York, Findings of Fact and Conclusions of Law in the Case of United States of America against National Lead Co., Titan Co., Inc., and E. I. du Pont de Nemours & Co., Inc., Civil 26-258, October 2, 1945.

The output of this new group of firms was readily absorbed by the world economy as it

emerged from the great depression of the 30's. The American Zirconium Corp. opened a plant at Baltimore, Md., in 1934 under a license agreement with Du Pont, which restricted the company to production of 3,000 short tons per year and caused it to pay a royalty of 2 percent on the price of all pigments shipped. Three years later American Zirconium was successful in having its quota raised to 6,000 tons. In 1941 the agreement was amended once more to permit the production of 9,000 short tons per year, and additional equipment was installed within the year to implement the new agreement. Production in the United States increased from 100 short tons in 1920 to 128,000 in 1941.

A few small independent producers were reported throughout the world during the 30's, although the majority were soon induced to join one of the larger groups. Such firms included Titan Products, Ltd., which operated two titanium-pigment plants at Brooklyn, Victoria, Australia; Van der Lands, which operated a titanium-pigment plant in the Netherlands, utilizing ilmenite obtained as a byproduct in the mining and concentrating of placer-tin ores in the East Indies; S. E. Goldschmidt & Sons, which operated a plant in Germany and marketed a composite pigment under the trade name of Titanal; Shai Industrial Chemical Co. and Dai Nippon Artificial Fertilizer Co., which operated three small titanium-pigment plants in Japan. Production outside the United States was only 28,000 short tons in 1938.

Before World War II the leading American manufacturers of titanium pigments obtained their supplies of ilmenite from India. After 1942 their supplies came mainly from domestic deposits. One of the chief sources of supply was the National Lead Co. mine at Tahawus, N. Y., which began production in August 1942. National Lead invested over \$10 million in this enterprise and offered participation in the project to each of the other producers of titanium pigments in the United States. Du Pont was the only producer to take advantage of this plan, but it allowed a 10-year purchase contract to expire in 1952 and has since relied mainly upon its mines in Florida.

DOMESTIC PRODUCERS

Production and shipments of titanium pigments in 1954 were slightly above the record set in 1953. Titanium pigments were produced by the American Cyanamid Co., Pigments Division, at Gloucester City, N. J., and Piney River, Va.; The Glidden Co., Chemicals-Pigments-Metals Division, at Baltimore, Md.; E. I. du Pont de Nemours & Co., Inc., at Edge Moor, Del., and Baltimore, Md.; and the National

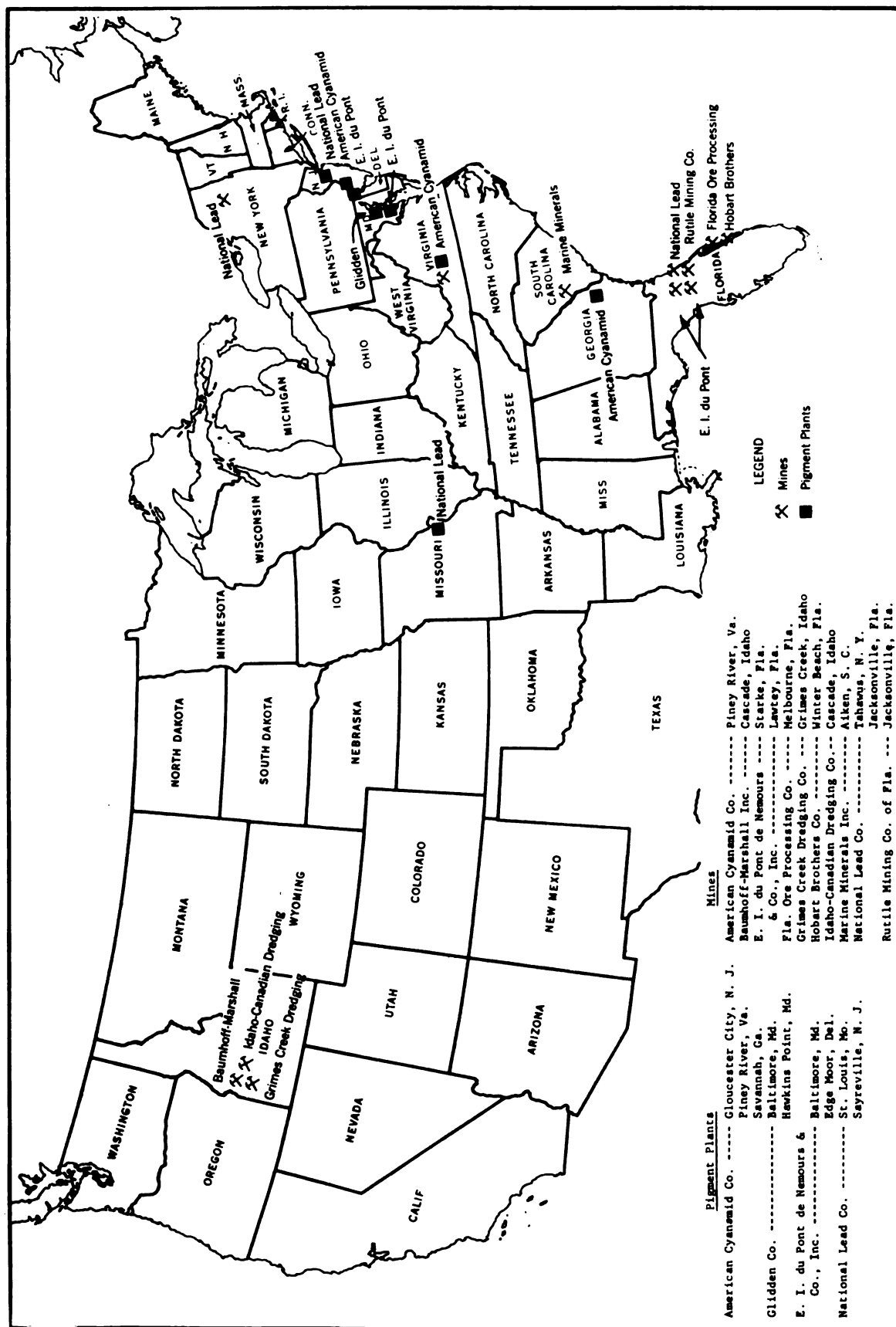


FIGURE 30.—Geographic Location of Titanium-Pigment Plants and Mines in the United States, 1955.

Lead Co., at St. Louis, Mo., and Sayreville, N. J. The geographical distribution of the titanium-pigment producers is shown in figure 30.

The New Jersey Zinc Co., New York, N. Y., announced on March 12, 1954, purchase of the American Cyanamid Co. titanium dioxide plant at Gloucester City, N. J. The turnover was scheduled to take place in the latter part of 1955, when American Cyanamid was to complete its new plant at Savannah, Ga. The Glidden Co. and the National Lead Co. announced plans for expanding titanium-pigment facilities in July 1954. Glidden planned construction of a titanium-pigment plant (rated at about 18,000 tons per year) at Hawkins Point, Md., with completion scheduled for the end of 1955. The cost of this facility was estimated at \$10 million. The National Lead Co. stated that it would erect new facilities at St. Louis, Mo., for an additional capacity of about 36,000 tons of titanium dioxide per year. Construction that began in 1954 was expected to be completed by July 1955.

MANUFACTURERS OF ALLOYS AND CARBIDE

The first titanium company in the United States was the Titanium Alloy Manufacturing Co., which constructed a plant at Niagara Falls, N. Y., in 1906 to produce ferrocobalt-titanium. This plant, acquired by National Lead Co. in 1948, is now designated as the Titanium Alloy Manufacturing Division of National Lead and continues to be one of the major suppliers of titanium ferroalloys. The major consumers of titanium minerals or titanium dioxide for alloys and carbide in 1954 were as follows:

Company:	Location
Aluminum Co. of America...	Massena, N. Y.
	Point Comfort, Tex.
	Vancouver, Wash.
American Smelting & Refining Co.	Los Angeles, Calif.
	Perth Amboy, N. J.
Carolina Aluminum Co.....	Badin, N. C.
Fansteel Metallurgical Co.....	North Chicago, Ill.
Firth Sterling, Inc.....	McKeesport, Pa.
Kaiser Aluminum & Chemical Corp.	Spokane, Wash.
Kennametal, Inc.....	Latrobe, Pa.
Metal Carbides, Inc.....	Youngstown, Ohio
Metal Hydrides, Inc.....	Beverly, Mass.
Metal & Thermit Corp.....	Carteret, N. J.
Reynolds Metals Co.....	Troutdale, Oreg.
Titanium Alloy Manufacturing Division of National Lead.	Niagara Falls, N. Y.
Union Carbide & Carbon Corp.	Do.
Universal Cyclops Steel Corp.	Do.
Vanadium Corp. of America...	Cambridge, Ohio.
	Niagara Falls, N. Y.

Broken down specifically into products produced, the following companies manufacture ferrotitanium: Metal & Thermit Corp., Titanium Alloy Manufacturing Division of National Lead, Union Carbide & Carbon Corp., and Vanadium Corp. of America.

The following companies use titaniferous material in preparing aluminum master alloys: Aluminum Co. of America, American Smelting & Refining Co., Carolina Aluminum Co., Kaiser Aluminum & Chemical Corp., and Reynolds Metals Co.

Miscellaneous other master alloys, such as cuprotitanium and nickel-titanium, are also produced by Metal Hydrides, Inc., Titanium Alloy Manufacturing Division of National Lead, and Vanadium Corp. of America.

Titanium carbide is produced by: Fansteel Metallurgical Co., Firth Sterling, Inc., Kennametal, Inc., and Metal Carbides, Inc.

Figure 31 shows how these companies are grouped geographically in the United States. The majority of these companies consumed rutile, the ferroalloy producers being the only ones that used ilmenite. The carbide producers were the only companies using manufactured titanium dioxide in addition to rutile.

MANUFACTURERS OF WELDING-ROD COATINGS

In the past, one of the major uses of rutile has been as a constituent of welding-rod coatings. Because of the rising price and shortness of supply of rutile, the trend has been toward more widespread use of ilmenite, manufactured titanium dioxide, and titanium slag. Of the major consumers of titaniferous material for welding-rod coatings in the list that follows, only 2 did not use rutile, and only 5 did not use any manufactured titanium dioxide in 1954. About half of these companies also used some ilmenite in their welding-rod coatings. The major consumers of titaniferous material for welding-rod coatings in 1954 were: (See also fig. 32 for the geographic distribution of these producers.)

Company:	Location
American Brake Shoe Co....	Chicago Heights, Ill.
American Chain & Cable Co.	Monessen, Pa.
A. O. Smith Corp.....	Milwaukee, Wis.
A. P. Johnston.....	Los Angeles, Calif.
Arcos Corp.....	Philadelphia, Pa.
Arcorods Corp.....	Cuyahoga Heights, Ohio.
	Sparrows Point, Md.
Champion Rivet Co.....	Cleveland, Ohio.
Combustion Engineering Superheater, Inc.	Chattanooga, Tenn.
Harnischfeger Corp.....	Milwaukee, Wis.
Hobart Bros. Co.....	Troy, Ohio.
Hollup Corp.....	Chicago, Ill.

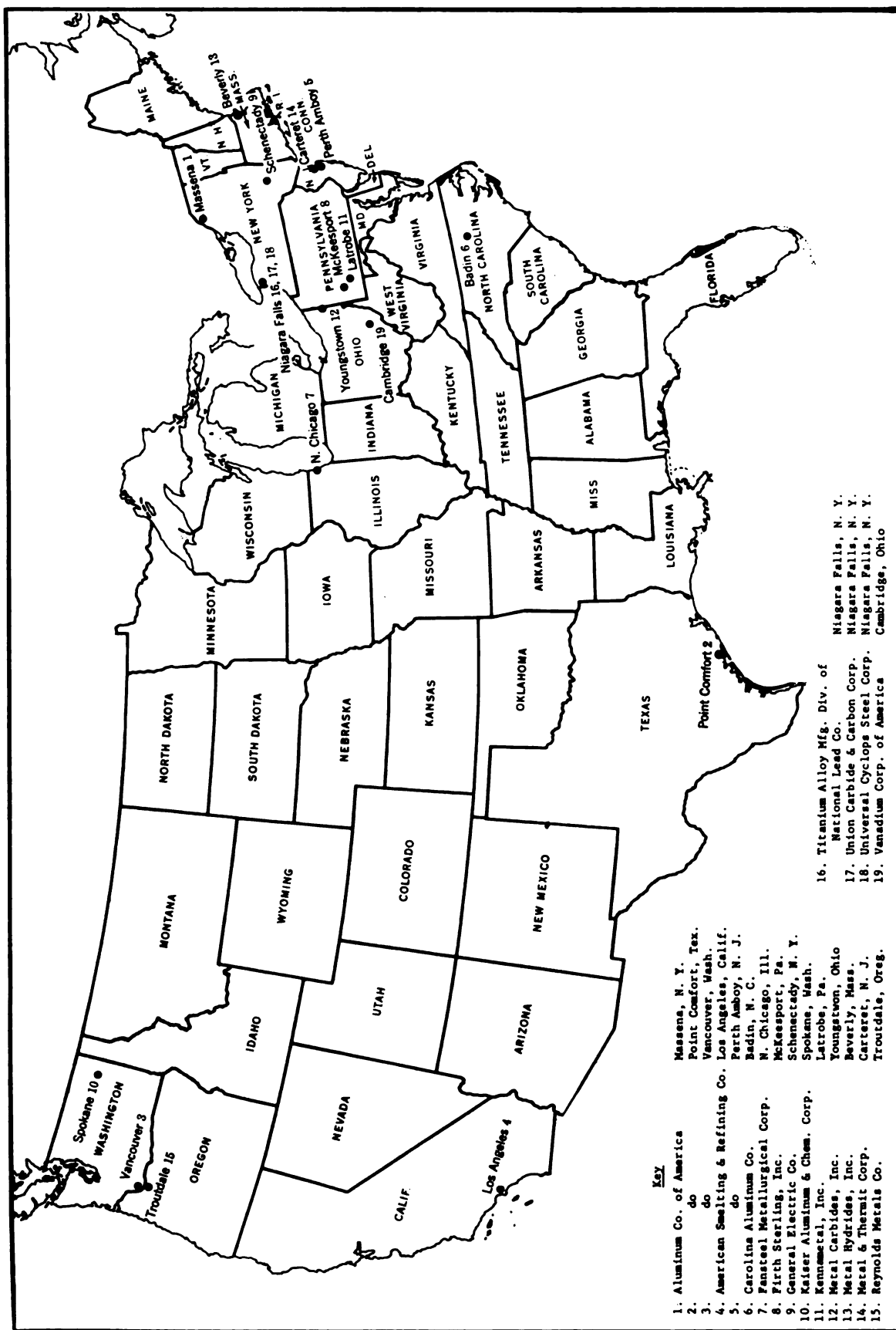


FIGURE 31.—Geographic Location of Major Producers of Titanium Alloys and Carbides in the United States, 1955.

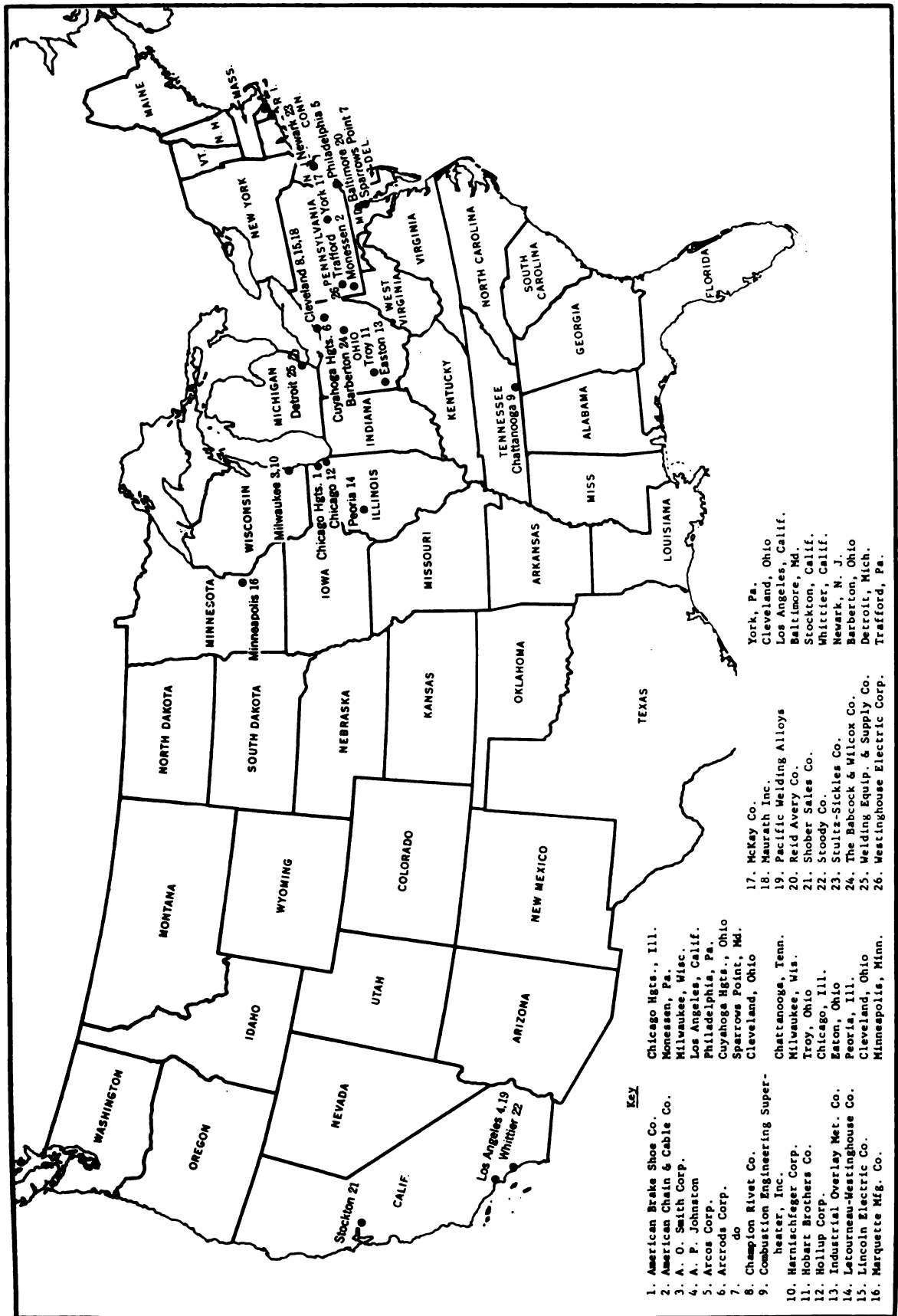


FIGURE 32.—Geographic Location of Major Producers of Titaniferous Welding-Rod Coatings in the United States, 1955.

Company:	Location
Industrial Overlay Metals, Inc.	Eaton, Ohio.
LeTourneau-Westinghouse Co.	Peoria, Ill.
Lincoln Electric Co.	Cleveland, Ohio
Marquette Manufacturing Co.	Minneapolis, Minn.
McKay Co.	York, Pa.
Maurath, Inc.	Cleveland, Ohio.
Pacific Welding Alloys	Los Angeles, Calif.
Reid Avery Co.	Baltimore, Md.
Shober Sales Co.	Stockton, Calif.
Stoody Co.	Whittier, Calif.
Stultz-Sickles Co.	Newark, N. J.
The Babcock & Wilcox Co.	Barberton, Ohio.
Welding Equipment & Supply Co.	Detroit, Mich.
Westinghouse Electric Corp.	Trafford, Pa.

PATENTS THAT AFFECT THE INDUSTRY

The section on patents in chapter 14 lists some of the numerous patents that affect the titanium industry. The list is by no means complete but does furnish a cross section of the patents in effect in 1955. The Titanium Bibliography—1900–51, prepared by Battelle Memorial Institute, gives an extensive coverage of patents issued before 1951.

Perhaps the most important patent affecting the metal industry is that covering the Kroll process; therefore, the history of this patent will be discussed in some detail.

KROLL PATENT

The basic process for producing titanium sponge metal commercially as of 1954 (titanium tetrachloride reduction with magnesium in an inert atmosphere) was patented by Dr. William (Wilhelm) J. Kroll in Germany in 1938 and in the United States in 1940. The United States patent (No. 2,205,854) was vested in the Alien Property Custodian in 1943, under the authority of the Trading With the Enemy Act. In addition, the contract rights of Siemens & Halske, A. G., a corporation organized under the laws of Germany, as exclusive licensee under the patent, were vested in the Attorney General in 1948, he having succeeded to the powers of the Alien Property Custodian. After the vestings the patent and contract rights therein were the subject of a suit brought by Dr. Kroll against the Attorney General. The judgment, which was entered on April 3, 1951, required the Attorney General to convey the legal title to the patent to Dr. Kroll but provided that the Attorney General was entitled to retain an exclusive license in and to the patent, a right to sublicense others under the patent, and a right to share equally with Dr. Kroll in the royalties from sublicensees. The royalties were to be at rates agreed to by the Attorney General and Dr. Kroll or, in the absence of such an agreement, at rates set by an order of the court. The parties were not able to reach such an agreement; and the court, by an order entered on December 1, 1953, established the following per annum rates at which the Attorney General is authorized to grant sublicenses:

(1) Five percent of the gross sales price of the first 50,000 pounds of titanium sold; (2) 3 percent of the gross sales price of the next 50,000 pounds of titanium sold; and (3) 1 percent of the gross sales price of all titanium sold in excess of 100,000 pounds. Sublicensees at these rates may be granted, retroactive to April 3, 1951. Such licenses may be obtained from the Office of Alien Property, United States Department of Justice, Washington 25, D. C. The patent expires June 25, 1957.

MANUFACTURERS OF CERAMICS

A large number of companies used ilmenite or rutile in ceramics, but the amount used by each company was generally less than 1 ton. The major consumers of ilmenite or rutile for ceramic applications used it in manufacturing frit, glazes, and porcelain and as a colorant for vitrified ceramic dinnerware. A substantial tonnage of manufactured titanium dioxide was also consumed in manufacturing frit. The major consumers of ilmenite and rutile for ceramic uses in 1954 follow:

Company:	Location
American Radiator & Standard Sanitary Co.	Baltimore, Md. Louisville, Ky. Richmond, Calif.
Buffalo Pottery Co.	Buffalo, N. Y.
Cambridge Tile Manufacturing Co.	Cincinnati, Ohio.
Federal Enameling & Stamping Co.	McKees Rocks, Pa.
Frankoma Potteries, Inc.	Sapulpa, Okla.
Lisk-Savory Corp.	Canandaigua, N. Y.
Olean Tile Co.	Olean, N. Y.
Wallace China Co., Ltd.	Huntington Park, Calif.
Wheeling Tile Co.	Wheeling, W. Va.

MANUFACTURERS OF FIBERGLASS

Titanium also finds application in the manufacture of fiberglass because it has the ability to shrink the fibers. Manufacturers using titanium for this purpose in 1954 were as follows:

Company:	Location
Corning Glass Co.	Charleroi, Pa. Corning, N. Y.
Gustin-Bacon Manufacturing Co.	Kansas City, Mo.
L. O. F. Glass Fibers Co.	Parkersburg, W. Va.
Owens-Corning Fiberglass Co.	Toledo, Ohio.
Pittsburgh Plate Glass Co.	Ford City, Pa. Shelbyville, Ind.

Half of the companies listed used rutile, and about half used manufactured titanium dioxide for fiberglass. None of these companies used ilmenite for this purpose.

CHAPTER 8. SUPPLY AND DISTRIBUTION

WORLD PRODUCTION

CONCENTRATES

World production figures for ilmenite and rutile concentrates for 1935-54 are shown in tables 48 and 49. Because of the great difference in total production of ilmenite (of the magnitude of hundred thousand tons) and the total production of rutile (of the magnitude of ten thousand tons), it is difficult to show individual production of the two on the same chart. Figures 33 and 34 graphically depict world production of ilmenite and rutile, by countries, for 1925-54.

In terms of tonnage, ilmenite concentrate comprised 95 percent of the total world production of titanium minerals in 1954. The ratio of ilmenite tonnage to the total tonnage did not fall below 92 during any year from 1925 to 1954.

ILMENITE

The average percentages of the total ilmenite production by the principal producing countries from 1950-54 follow: United States, 51; India, 23; Norway, 13; Canada, 7; and Malaya, 4.

Indian production of ilmenite increased steadily from 1925-39, and India was the world's leading producer of ilmenite from 1927 until 1942. Market disturbances during World War II caused India to be surpassed by the United States and Norway in the production of ilmenite during 1942 and 1943. Since 1944 India has been the second largest producer of ilmenite in the world.

United States ilmenite production has been greater than that of any other country every year from 1942-54. In 1942 United States production was 35 percent of the world production, and the annual percentage has varied between 45 and 55 from 1943-54.

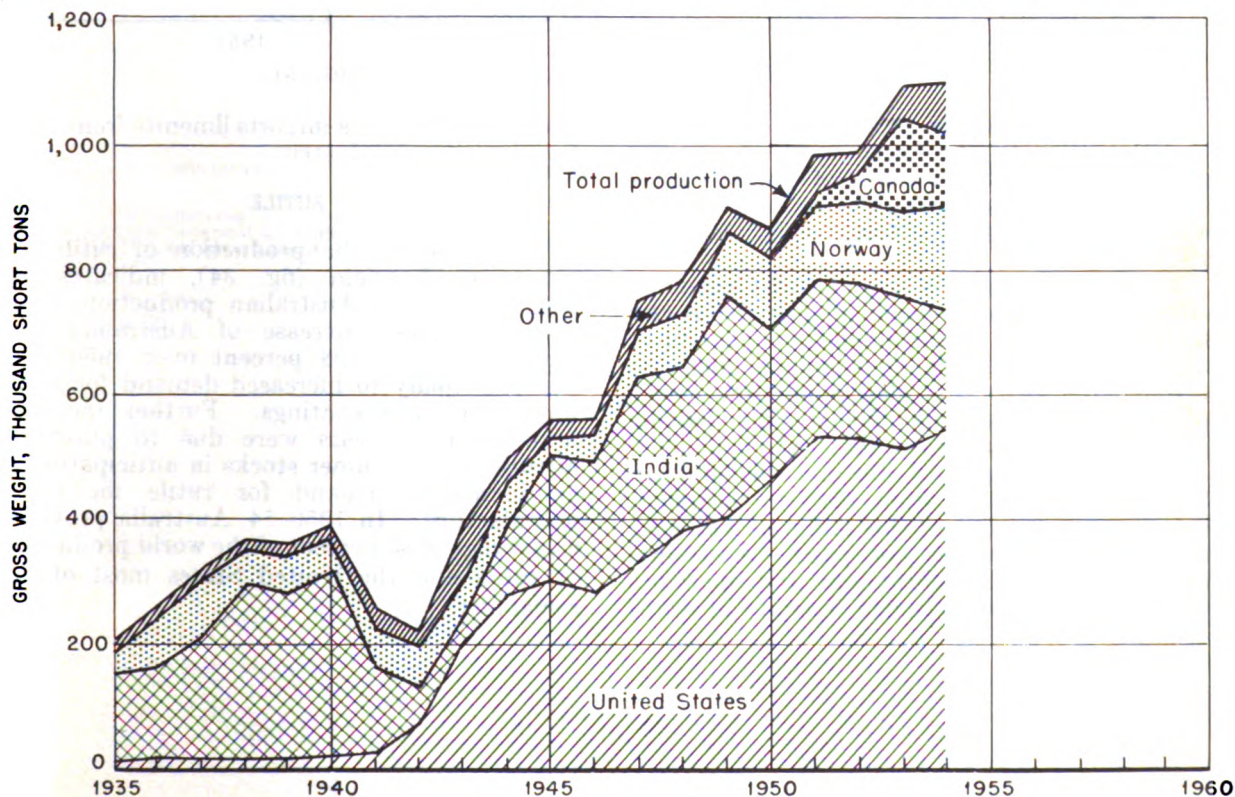


FIGURE 33.—World Production of Ilmenite, by Countries, 1935-54.

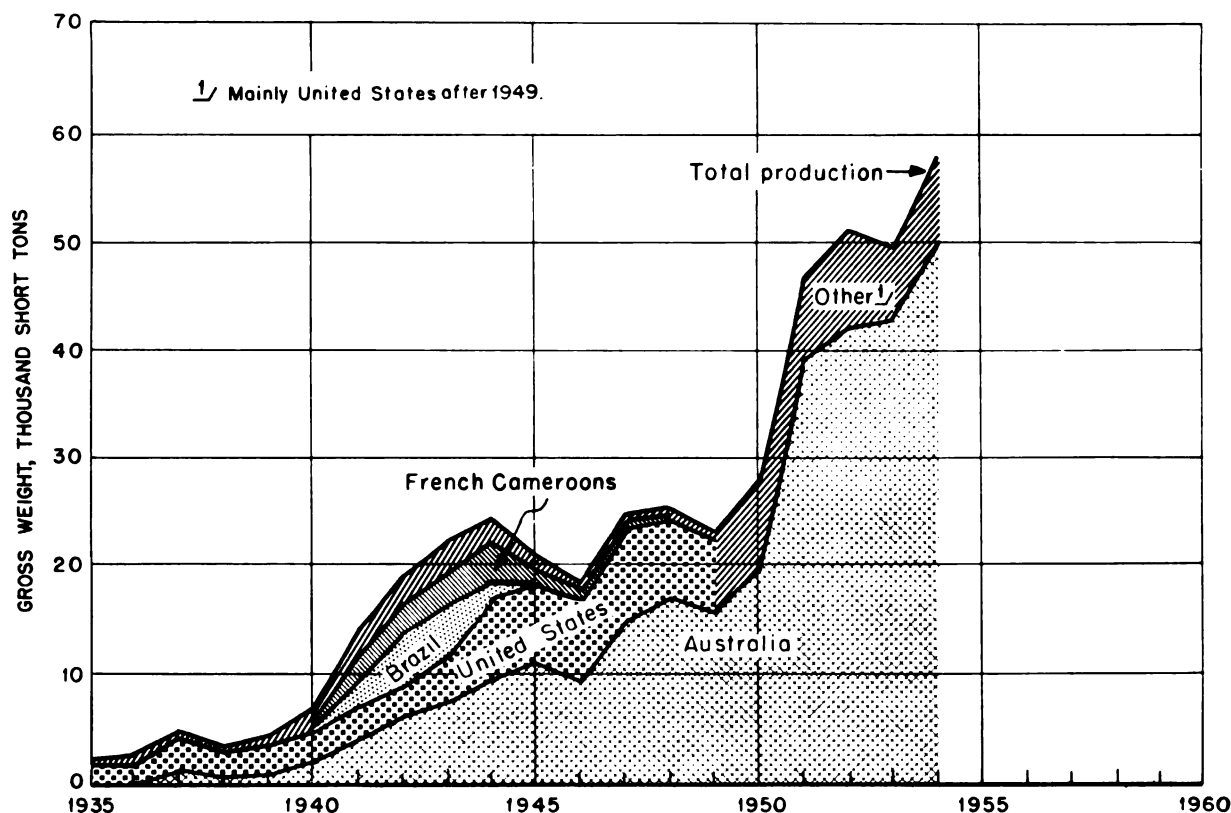


FIGURE 34.—World Production of Rutile, by Countries, 1935-54.

The annual ilmenite production of Norway, the third largest producer in 1944-53, has been rather steady in terms of tonnage since 1938, the highest production being from 1948-54 and the maximum (164,448 short tons) in 1954.

Titanium-slag production caused Canada to emerge as a major producer of titaniferous raw material in 1951. Canada had been a producer of titanium minerals in varying amounts through the years, but slag production firmly placed Canada among the world's leading producers of titaniferous material.

Australia's output of ilmenite varied from 5,000 to 12,000 tons from 1943-49; however, only a small amount of this material was sold, and the remainder was stockpiled. Australian ilmenite is high in chromium and therefore cannot compete with Indian ilmenite in world

markets. Australia imports ilmenite from India for its pigment industry.

RUTILE

The graph of the production of rutile, by countries of origin (fig. 34), indicates the predominance of Australian production. The relatively great increase of Australian production in 1951 (98 percent over 1950) was due principally to increased demand for rutile for welding-rod coatings. Further increases in subsequent years were due to purchases of rutile for consumer stocks in anticipation of an increased demand for rutile for metal manufacture. In 1950-54, Australia provided an average of 83 percent of the world production of rutile and the United States most of the remainder.

TABLE 48.—*World production of ilmenite concentrate, 1925-54*

[In short tons]

Year	Aus- tralia ¹	Bra- zil ²	Canada	Egypt	India	Ja- pan ³	Ma- laya ²	Nor- way	Por- tugal	Seneg- al ⁴	Spain	United States	Total
1925		1, 653	3, 978		366			4, 588	3	200		5, 566	16, 400
1926		1, 651	200		4, 741			4, 630	1, 135	6, 376		4, 813	23, 500
1927		1, 441	2, 029		19, 946			6, 320	775	5, 732		3, 500	39, 700
1928		1, 651	2, 244		28, 344			8, 761	775	2, 326		978	45, 100
1929		7, 012	2, 748		26, 511			8, 734	62	7, 981		16	53, 100
1930		88	412		32, 229			8, 411	919	5, 866		533	48, 500
1931			1, 509		40, 505			5, 512	168	11		350	48, 100
1932				487	56, 059			14, 860	844			352	72, 600
1933	616				59, 337		225	25, 588	711			3, 540	90, 000
1934			2, 023	181	84, 721		56	28, 997	478	540		10, 445	127, 400
1935			2, 228	202	142, 297		2, 800	41, 870	291	1, 378		9, 011	200, 100
1936		792	2, 566	26	155, 786		11, 437	74, 068	583	3, 557		10, 642	259, 500
1937	759	258	4, 228	349	200, 777		6, 934	92, 824	1, 605	3, 390		10, 531	321, 700
1938	364	171	207	99	282, 486		7, 123	54, 212	626	9, 299		13, 726	368, 300
1939	753	11	3, 694		266, 378		12, 233	60, 657	553	4, 705		14, 602	363, 600
1940	1, 695	13	4, 535	513	294, 731		2, 862	56, 989	991	7, 806		20, 668	390, 800
1941	4, 166	4, 928	12, 651	2	144, 525		49	67, 336	880	1, 102	78	23, 297	259, 000
1942	5, 057		10, 031	⁵ 762	55, 090			66, 925		5, 335	94	77, 209	220, 500
1943	6, 030		69, 436		42, 324			72, 963	133	805	196	203, 551	395, 400
1944	8, 032	3, 582	33, 973	10	112, 890			70, 520			604	278, 610	508, 200
1945	9, 363	5, 512	14, 147	51	192, 737			31, 208	332	3, 527	238	308, 516	565, 600
1946	7, 403		1, 405	161	207, 227			57, 953	698	4, 620	141	282, 447	562, 100
1947	11, 547		7, 104		292, 270		14, 651	76, 843	268	12, 436	165	336, 533	751, 800
1948	12, 959	8, 708	4, 441	1, 765	256, 946		14, 230	99, 227	171	4, 067	200	383, 745	786, 500
1949	10, 895	716	540	700	345, 162		22, 083	109, 143	1, 013	9, 191	414	407, 314	907, 200
1950	⁷ 56		⁸ 3, 502	287	238, 183		27, 905	115, 908	73	869	702	468, 320	855, 800
1951	⁷ 1, 403		⁸ 21, 203	359	250, 975		48, 712	116, 139	186	4, 311	772	535, 835	980, 000
1952	⁷ 52		⁸ 42, 192	2, 202	251, 983		24, 502	130, 370	476	5, 095	1, 410	528, 588	987, 000
1953	(⁷)		⁸ 146, 614	843	240, 946	2, 028	29, 758	141, 220	746	3, 858	1, 582	513, 696	1, 081, 000
1954	(⁹)		⁸ 124, 162	248	186, 612	2, 627	50, 114	164, 448	543	13, 779	1, 269	547, 711	1, 092, 000
1955													
1956													
1957													

¹ Estimated ilmenite content of all titanium-mineral-bearing concen-
trates.² Exports.³ Represents titanium slag.⁴ Approximately 20 percent of ilmenite concentrate is zircon.⁵ Includes 26 tons of garnet ilmenite.⁶ Includes a mixed product containing altered ilmenite, leucoxene, and
rutile.⁷ Due to high chromium content, only sales are shown.⁸ Includes titanium slag containing approximately 70 percent TiO₂.⁹ Data not available; estimate included in total.

TABLE 49.—*World production of rutile concentrate, 1925-54*

Year	Aus- tralia ¹	Brazil ²	French Came- roon	French Equa- torial Africa	India	Norway	Senegal	South West Africa	United States	Total
1925						52			42	100
1926						55			30	100
1927						50			334	400
1928						65			521	600
1929						47				100
1930						51			497	600
1931						23			354	400
1932		39				33			347	400
1933		106				62				200
1934		116				247			695	1,100
1935		316	50			137			1,670	2,200
1936		847	61			218		60	1,391	2,600
1937	1,257	416	114			206		18	2,791	4,800
1938	³ 513	416	³ 130		36	137			2,132	3,400
1939	791	539	³ 176		207	183			2,515	4,400
1940	1,811	550	441		1,030	172			2,888	6,900
1941	4,206	2,611	1,984		2,084	190			3,130	14,200
1942	6,066	5,087	2,646		2,530	85			2,648	19,100
1943	7,418	5,023	3,015		2,641	128			3,987	22,200
1944	9,748	1,724	3,660		1,843	94			6,922	24,000
1945	10,914	176	1,587		683	84			7,179	20,600
1946	9,130	31	1,389		289	69			7,453	18,400
1947	14,777	6	832		176	56			8,562	24,400
1948	16,918		635		142				7,380	25,100
1949	15,386		444			18			7,008	22,900
1950	19,825	6	28	7	41	34			7,535	27,500
1951	39,170		119		51	20	3		7,189	46,600
1952	41,800	19	324		164	47	29		7,125	49,500
1953	42,604		58		117	3			6,825	49,600
1954	50,018		³ 179		117	(⁴)			7,411	57,800
1955										
1956										
1957										

¹ Estimated rutile content of all titanium-mineral-bearing concentrates.
² Exports.

³ In addition, 98 tons of zircon-rutile-ilmenite concentrate was produced.
⁴ Data not available; estimate included in total.

METAL

World production of titanium sponge is summarized in the following table:

TABLE 50.—*World production of commercially pure titanium metal,¹ 1948-54, in short tons*

Year	United States	Japan	United Kingdom	Total
1948	² 10			10
1949	² 25			25
1950	² 75			75
1951	495			495
1952	1,075	9		1,084
1953	2,241	77		2,318
1954	5,370	673	94	6,137
1955				
1956				
1957				

¹ Unconsolidated metal in various forms.
² Estimate.

The figures in the above table are for production on a commercial and semicommercial scale only and do not include metal made in laboratory operations. From the above data it may be seen that domestic production of

titanium sponge has doubled every year since 1951. Although the Japanese industry is comparatively young, its production pattern seems to be following that set by the United States industry in its earlier years. Most of the sponge produced in Japan was exported to other countries as no market for titanium metal existed in Japan in 1954. The chief customers for Japanese titanium sponge in 1954 were the United States (254 tons) and the United Kingdom (219 tons).

Production of crude titanium metal from the United Kingdom should increase significantly when the Imperial Chemical Industry plant at Witton gets into operation.

DOMESTIC PRODUCTION

CONCENTRATES

Table 51 gives United States production of concentrates of ilmenite and rutile, in short tons, for 1925-54 and shipments of these minerals from 1939-54.

TABLE 51.—United States production and shipments of ilmenite and rutile, 1925-54, in short tons

Year	Ilmenite				Rutile			
	Production	Shipments ¹			Production	Shipments ²		
		Gross weight	TiO ₂ content	Value		Gross weight	TiO ₂ content	Value
1925	5,566				46			
1926	4,813				30			
1927	3,500				334			
1928	918				521			
1929	16							
1930	533				497			
1931	350				354			
1932	352				347			
1933	3,540							
1934	10,445				695			
1935	9,011				1,670			
1936	10,642				1,391			
1937	10,531				2,791			
1938	13,726				2,132			
1939	14,602	16,872	7,668	\$137,042	2,515			
1940	20,668	20,702	9,505	183,686	2,888	2,657	2,475	\$393,243
1941	23,297	21,526	9,930	196,522	3,130	3,431	3,192	493,782
1942	77,208	93,397	41,328	1,805,823	2,648	2,649	2,466	410,956
1943	203,551	211,715	94,283	3,738,970	3,987	3,941	3,639	610,879
1944	278,610	280,791	128,095	7,371,279	6,922	6,770	6,312	1,088,112
1945	308,516	308,518	141,852	7,359,170	7,179	6,837	6,414	869,920
1946	282,447	282,708	130,624	4,878,917	7,453	7,514	7,046	996,989
1947	336,533	336,061	157,328	5,029,490	8,562	5,157	4,813	533,548
1948	383,745	381,508	177,447	5,793,973	7,380	9,907	9,226	647,334
1949	³ 407,314	³ 394,214	190,755	6,343,568	7,008	5,579	5,194	358,578
1950	³ 468,320	³ 452,370	230,826	5,606,584	7,535	6,676	6,213	356,100
1951	³ 535,835	³ 510,840	261,982	7,689,272	7,189	10,919	10,166	545,000
1952	³ 528,588	³ 522,515	265,596	8,022,752	7,125	6,874	6,416	715,491
1953	³ 513,696	³ 512,176	258,247	7,222,641	6,825	6,476	6,043	702,791
1954	³ 547,711	³ 531,895	270,651	7,375,344	7,411	7,305	6,822	869,677
1955								
1956								
1957								

¹ Data not available before 1939.² Data not available before 1940.³ Includes a mixed product containing altered ilmenite, leucoxene, and rutile.

Shipments of ilmenite for 1939-46 exceeded production. To accomplish this, stocks at the mines were depleted during those years. After 1946 mine stocks were again built up.

The shipments of rutile approximated production for 1939-41, inclusive, but varied somewhat during the years from 1942-51. These variations were due principally to fluctuations in the demand for welding rods.

Although exact production data cannot be given by States because they would reveal individual company operations, it may be stated that, of the total ilmenite production in 1954, New York supplied over half and Florida almost one-third and that the remainder was supplied by Virginia and Idaho. Since 1949 all rutile production has originated in Florida.

METAL

In 7 years the titanium-metal industry progressed from a production of 10 tons in 1948 to 5,370 short tons in 1954. Table 50 lists the domestic production of titanium sponge from 1948 to 1954. A more extensive discussion of production may be found in chapter 1 under Titanium Metal, as it was necessary to list production of metal to give some idea of the amount of rutile consumed in producing sponge.

No figures are available for the amount of mill products manufactured in these years; but in 1953, 1,114 short tons of mill products was shipped, and in 1954 1,299 short tons. Since it is usually the practice of the melters to produce only mill products to fulfill definite orders, these figures probably are a close

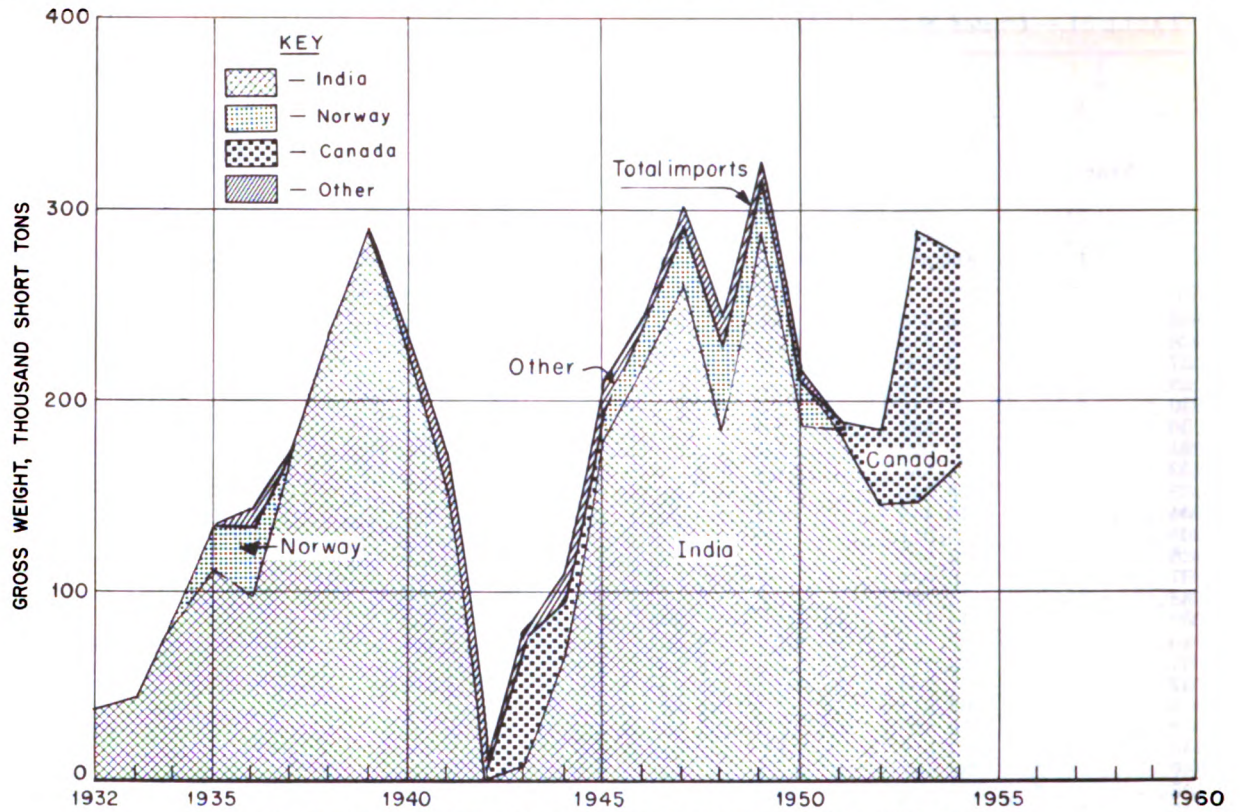


FIGURE 35.—Imports of Ilmenite, by Countries of Origin, 1932-54.

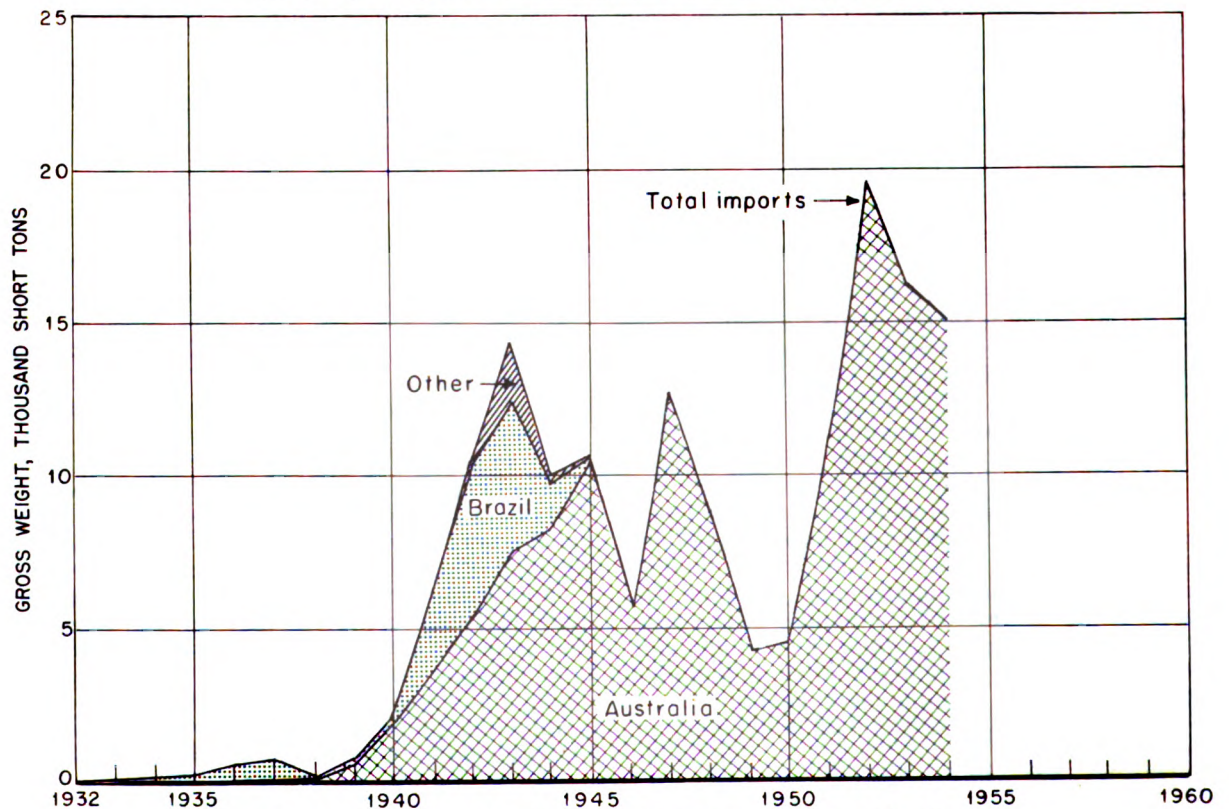


FIGURE 36.—Imports of Rutile, by Countries of Origin, 1932-54.

TABLE 52.—*Titanium concentrates*¹ imported for consumption in the United States, 1928-54

(In short tons)

Ilmenite					Rutile			
Year	As reported	In "zirconium ore" ²	Total	Value of "as reported"	As reported	In "zirconium ore" ²	Total	Value of "as reported"
1928.....	17, 224	-----	17, 224	\$79, 640	-----	-----	-----	-----
1929.....	25, 052	-----	25, 052	104, 887	6	-----	6	\$1, 463
1930.....	24, 974	-----	24, 974	150, 466	3	-----	3	974
1931.....	33, 440	-----	33, 440	144, 951	1	-----	1	189
1932.....	37, 509	-----	37, 509	231, 652	88	-----	88	4, 508
1933.....	43, 243	-----	43, 243	196, 211	79	-----	79	3, 737
1934.....	80, 316	-----	80, 316	356, 208	155	-----	155	7, 350
1935.....	134, 313	-----	134, 313	636, 293	212	-----	212	13, 124
1936.....	142, 740	-----	142, 740	697, 822	510	-----	510	38, 552
1937.....	172, 472	-----	172, 472	770, 757	665	-----	665	67, 643
1938.....	234, 275	-----	³ 234, 141	1, 018, 403	230	-----	³ 364	26, 533
1939.....	286, 576	615	287, 191	1, 126, 200	442	345	787	23, 170
1940.....	221, 641	2, 250	223, 891	750, 590	156	2, 008	2, 164	14, 849
1941.....	166, 846	3, 843	170, 689	629, 940	3, 114	3, 177	6, 291	306, 176
1942.....	7, 227	3, 180	10, 407	60, 490	6, 423	4, 102	10, 525	623, 917
1943.....	74, 787	3, 306	78, 093	380, 161	9, 635	4, 703	14, 338	823, 624
1944.....	104, 884	4, 064	108, 948	596, 034	3, 699	6, 320	10, 019	272, 283
1945.....	208, 836	1, 236	210, 072	1, 217, 339	3, 304	7, 298	10, 602	98, 170
1946.....	240, 952	1, 388	242, 340	1, 440, 112	4, 408	1, 456	5, 864	213, 795
1947.....	301, 311	-----	301, 311	1, 791, 020	7, 576	-----	⁴ 12, 637	468, 810
1948.....	242, 119	-----	242, 119	1, 758, 838	8, 771	-----	8, 771	588, 713
1949.....	324, 157	-----	324, 157	2, 479, 071	3, 085	1, 096	4, 181	179, 746
1950.....	216, 459	-----	216, 459	1, 198, 545	3, 427	1, 133	4, 560	149, 733
1951.....	⁵ 189, 078	-----	⁵ 189, 078	1, 323, 438	11, 023	210	11, 233	491, 383
1952.....	⁵ 184, 013	-----	⁵ 184, 013	2, 478, 077	19, 394	156	19, 550	1, 728, 803
1953.....	⁵ 286, 644	-----	⁵ 286, 644	5, 463, 526	16, 098	84	16, 182	1, 791, 494
1954.....	⁵ 275, 005	-----	⁵ 275, 005	4, 993, 402	14, 965	95	15, 060	1, 323, 183
1955.....	-----	-----	-----	-----	-----	-----	-----	-----
1956.....	-----	-----	-----	-----	-----	-----	-----	-----
1957.....	-----	-----	-----	-----	-----	-----	-----	-----

¹ Classified as "ore" by U. S. Department of Commerce. Data not available before 1928.

² Ilmenite and rutile, respectively, contained in Australian "zirconium ore," as reported by importers.

³ Data adjusted to apportion ilmenite and rutile in ore classified as "ilmenite" by U. S. Department of Commerce.

⁴ Includes rutile content of ilmenite ore as reported to the Bureau of Mines by importers.

⁵ Includes titanium slag.

approximation of actual production. From this it may be seen that, although sponge production in 1954 doubled that in 1953, production of mill products remained fairly constant.

IMPORTS CONCENTRATES

Table 52 and figures 35 and 36 show the tonnages of ilmenite and rutile imported for United States consumption during the period 1938-54. The extreme minimum of ilmenite imports in 1942 was due to virtual cessation of imports from India. Meanwhile, rutile imports from Australia increased in 1942 because shipping space from this area was available. As in the case of world production, the ratio of the import tonnage of ilmenite to that of rutile is relatively constant, the ilmenite concentrate making up 95 percent of the aggregate tonnage imported in 1954.

ILMENITE

Imports for consumption of ilmenite, by countries of origin, are shown in table 53 and figure 35. Historically India has provided most of the ilmenite imports, and relatively small quantities have come from Norway. Since 1951 the second most important source of imports has been Canada. All ilmenite imported in 1954 was from India and Canada. Most of the imports from Canada since 1951 have been titanium slag.

RUTILE

The imports for consumption of rutile, by countries of origin, are shown in table 53 and figure 36. Australia has provided the greater part of the annual imports since 1944, substantial quantities being contained in zirconium concentrate.

METAL

The first substantial quantity of crude titanium metal imported into the United States

TABLE 53.—Titanium concentrates ¹ imported for consumption, by countries of origin, 1939-54

[In short tons]

ILMENITE

Year	Australia	Australia, in zirconium ore ²	Brazil	Canada	Ceylon	Egypt	France	India	Malaya	Norway	Portugal	United Kingdom
1934								80,316				
1935				106				109,038		25,169		
1936								97,127		35,981		9,632
1937								170,232				2,240
1938	139				32			234,103				
1939	28	615						286,548				
1940	2	2,250	2					221,637				
1941	364	3,843	3,709	5,725				156,079			969	
1942	235	3,180	1,287	4,540				1,165				
1943	390	3,306		65,437				8,960				
1944	79	4,064	5,511	32,580	4,648			62,066				
1945	1,753	³ 1,236	10,508	6,987				179,693		9,895		
1946		1,388	2	1,250				218,623		21,077		
1947	1,659		1	7,122				262,503		30,026		
1948	(⁴)		8,708	4,519				184,309	3,335	41,248		
1949				540	2	721		289,739		33,155		
1950	112			1,357			1	187,834		27,155		
1951	100		1	⁵ 3,776				185,145	56			
1952				⁶ 38,451				145,562				
1953	54			⁶ 139,585				147,005				
1954				⁶ 107,521				167,484				
1955												
1956												
1957												

RUTILE

Year	Australia	Australia, in ilmenite ⁷	Australia, in zirconium ore ⁸	Brazil	Canada	French Cameroons	India	Norway	Portugal
1934				155					
1935				212					
1936	5			498	7				
1937	2			662	2				
1938	28			202					
1939	343		345	99					
1940	22		2,008	128					6
1941	666		3,177	2,448					
1942	1,311		4,102	4,966		⁹ 146			
1943	2,802		4,703	4,920		⁹ 1,095	818		
1944	1,896		6,320	1,669			134		
1945	3,070		7,298	234					
1946	4,377		1,456	31					
1947	7,460	5,061				3	113		
1948	8,771							(⁴)	
1949	3,085		1,096						
1950	3,427		1,133						
1951	11,023		210						
1952	19,394		156						
1953	16,098		84						
1954	14,965		95						
1955									
1956									
1957									

¹ Classified as "ore" by U. S. Department of Commerce. Data not available before 1934.² Ilmenite content of zirconium ore as reported to the Bureau of Mines by importers.³ Includes 309 tons not recovered from mixed concentrates.⁴ Less than 1 ton.⁵ Includes titanium slag.⁶ Chiefly all titanium slag, averaging 70 percent TiO₂.⁷ Rutile content of ilmenite ore as reported to Bureau of Mines by importers.⁸ Rutile content of zirconium ore as reported to Bureau of Mines by importers.⁹ Includes quantities reported by the U. S. Department of Commerce as originating in French Equatorial Africa, from which no rutile production has been recorded.

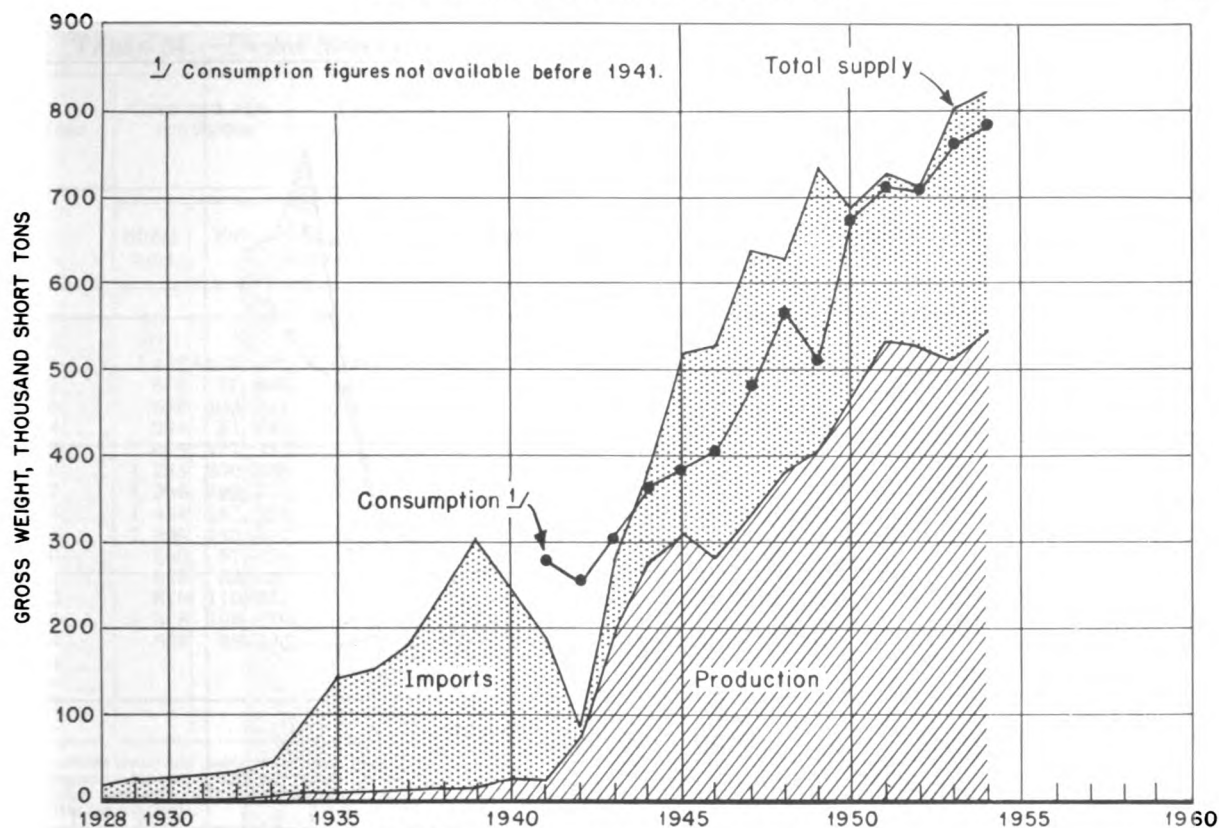


FIGURE 37.—Domestic Production, Imports, and Consumption of Ilmenite, 1928-54.

was shipped in from Canada (500 pounds) and France in 1952. The value of the metal imported that year was \$2,500. In 1953 the United States imported 10 pounds of crude metal from Canada and 71,299 pounds from Japan, with a total value of \$269,259. Receipts of commercially pure sponge from Japan increased to 386,100 pounds of metal valued at \$1,375,200 in 1954.

TOTAL DOMESTIC SUPPLY OF CONCENTRATES

Figures 37 and 38 graphically summarize the titanium supply situation in the United States for the years 1928 to 1954. The excess of new supply above the consumption line indicates either material that was stockpiled or material that was exported; however, exports of titanium ore have been relatively small. In 1941-43 consumption of ilmenite exceeded the total new supply owing to drastic curtailment of imports from India; this situation was alleviated by a sharp increase in domestic production. From 1943-54 the new supplies of ilmenite have increased at an average rate of 11 percent per year. In this same period new supplies of

rutile increased at an average rate of 8 percent per year.

In the 10 years before World War II (1932-41), the United States produced an average of only 7 percent of its total new supply of ilmenite, but in the 10 years after the war (1945-54) the United States has mined an average of 67 percent of its total available supply. Domestic production of rutile in the 10-year prewar period averaged 87 percent of the total supply, while production in the postwar period averaged only 44 percent of total supply. The total supply of ilmenite available to the United States through production and imports averaged 68 percent of total world production in the 10-year prewar period and 79 percent in the 1945-54 period. During these same periods supplies of rutile averaged 51 percent of world production in the prewar period and 48 percent in the postwar period.

EXPORTS

Ilmenite and rutile are not treated separately in export figures, but statistics are available in terms of tonnage and value for concentrates, titanium ferroalloys, titanium tetrachloride, titanium dioxide and pigments, metal

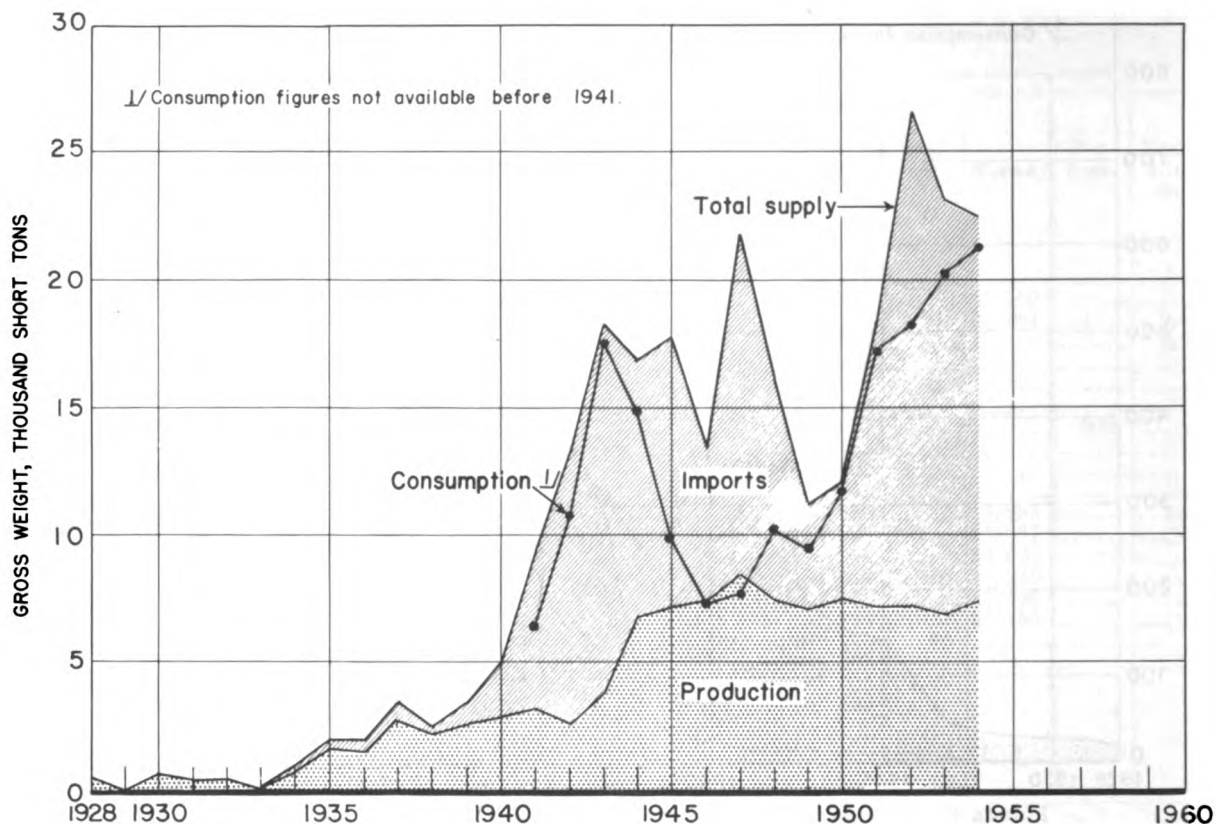


FIGURE 38.—Domestic Production, Imports, and Consumption of Rutile, 1928–54.

and alloys in crude form and scrap, and primary forms. From table 54 it may be seen that dioxide and pigments composed the greatest bulk of titanium exports from 1941–54. Dollar values of dioxide and pigment exports increased rather steadily from 1939–54; the increase averaged 30 percent each year.

The percentage of the total dollar value of all titanium exports making up the value of titanium dioxide and pigments, ores and concentrates, ferroalloys, and metal (crude, scrap, and primary forms) for 1946–54 follows:

Percentages of total value of titanium exports

	1946–51 (average)	1952	1953	1954
Dioxide and pigments.....	97.3	97.5	92.3	82.9
Ores and concentrates.....	1.8	1.0	.9	.3
Ferroalloys.....	.9	.8	.4	.1
Metal (crude, scrap, and primary forms).....		.7	6.4	16.7
Total.....	100.0	100.0	100.0	100.0

Metal exports became significant in 1953 and accounted for a comparatively large part of the total value of titanium exports in 1954.

Tonnagewise, exports of titanium dioxide and pigments reached a new peak in 1954, being 60 percent greater than the previous record set in 1953. Canada, the major recipient of titanium pigments, received 22,572 short tons. Other countries that received 1,000 tons or more follow, in short tons: Australia, 3,386; Belgium and Luxembourg, 2,799; Brazil, 2,056; Cuba, 1,362; France, 2,052; Italy, 1,298; Mexico, 2,495; Netherlands, 4,333; New Zealand, 1,010; Philippines, 1,107; Sweden, 1,086; Union of South Africa, 1,248; United Kingdom, 5,144; Venezuela, 1,365; and West Germany, 3,287. The remainder was distributed among 33 countries.

In 1954 exports of titanium concentrates decreased 52 percent from the peak set in 1953. Canada received 571 short tons and France, Mexico, and the United Kingdom the remaining 92.

Exports of metal, alloys, and scrap containing titanium increased from 2 tons in 1953 to 48 in 1954, with the United Kingdom the major recipient (47 tons).

Titanium-metal exports in semifabricated form increased from 31 short tons in 1953 to 164 in 1954. Major shipments went to the United

TABLE 54.—United States exports of titanium concentrates, alloys, and compounds, 1939–54

Year	Ores and concentrates		Titanium ferroalloys ¹		Titanium tetrachloride and other compounds ²		Dioxide and pigments		Metal and alloys in crude form and scrap ³		Primary forms, ⁴ n. e. c.	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1939	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	4,319	\$698,063	—	—	—	—
1940	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	4,962	867,535	—	—	—	—
1941	⁵ 432	⁵ \$70,613	⁵ 50	⁵ \$35,687	⁶ 17	⁶ \$5,792	7,821	1,609,071	—	—	—	—
1942	618	117,886	422	60,938	24	13,666	8,870	1,707,433	—	—	—	—
1943	576	103,947	760	117,402	728	442,591	9,765	1,830,344	—	—	—	—
1944	291	51,828	793	127,145	375	215,696	10,925	1,851,457	—	—	—	—
1945	609	121,951	744	122,887	75	46,718	12,824	2,315,552	—	—	—	—
1946	1,385	200,866	550	63,723	—	—	16,314	3,092,607	—	—	—	—
1947	1,266	192,703	509	80,590	—	—	21,171	5,183,936	—	—	—	—
1948	1,454	187,225	480	82,874	—	—	26,824	7,126,956	—	—	—	—
1949	1,505	143,412	179	40,918	—	—	29,621	8,140,991	—	—	—	—
1950	600	57,753	171	42,741	—	—	32,660	8,799,758	—	—	—	—
1951	646	63,050	175	107,718	—	—	39,242	13,274,143	—	—	—	—
1952	870	110,737	325	88,664	—	—	35,636	10,691,698	⁷ 762	⁷ \$31,134	3	\$38,979
1953	1,368	109,878	185	48,722	—	—	39,780	11,715,798	2	11,858	31	798,077
1954	663	85,896	172	39,885	—	—	63,802	23,281,039	48	1,107,582	164	3,567,054
1955	—	—	—	—	—	—	—	—	—	—	—	—
1956	—	—	—	—	—	—	—	—	—	—	—	—
1957	—	—	—	—	—	—	—	—	—	—	—	—

¹ Includes metal and nonferrous alloys, 1941–51.² Beginning January 1, 1946, not separately classified.³ Before January 1, 1962, not separately classified.⁴ Data not available.⁵ Data covers last 6 months only.⁶ Data covers last 4 months only.⁷ Includes material other than commercially pure titanium metal.

Kingdom (127 tons) and Canada (37 tons). Less than one-half ton was distributed among Australia, France, Sweden, and Switzerland.

Exports of titanium ferroalloys decreased 7 percent in 1954 from 1953. Shipments to Canada, the major recipient, totaled 148 tons, and the remaining quantity (25 tons) was shipped to Italy, France, Chile, Belgium, and Luxembourg.

STOCKS

Year-end stocks of ilmenite and rutile for 1941–54 are shown in table 55 and figures 39 and 40.

ILMENITE

The number of months of supply that these stocks represent can be determined by dividing the stocks by the current rate of consumption and then multiplying this figure by 12 months. For ilmenite this ratio has remained fairly constant since 1946, averaging 12 months of reserves on hand each year. The biggest drop in stocks took place in 1942, when they sank from a 15-month reserve in 1941 to an 8-month reserve. Stocks represented a 5-, 6-, and 9-month reserve in 1943, 1944, and 1945, respectively.

Historically ilmenite stocks have been almost

entirely in the hands of consumers (see fig. 40). This was due largely to the fact that the producer and consumer were often the same company. Total stocks of ilmenite declined steadily from the 1949 peak, but the decline was offset since 1952 by an increase in the stocks of titanium slag.

RUTILE

Stocks of rutile have been highly erratic. During World War II they never exceeded a 7-month supply and were as low as a 4-month supply in 1943. By 1946 they had climbed up to a 26-month reserve but decreased steadily to 1951, when there was only a 4-month supply on hand at the end of the year. From 1952–54 stocks were adequate to supply domestic needs for 10 months at the current rates of consumption.

Figure 40 shows that there has been considerable variation in the allocation of stocks among distributors, consumers, mines, and the Government. The proportion of stocks in the hands of consumers has been trending upward since 1948. Mine stocks have been subject to much variation. Government stocks referred to in the table and figure were those acquired for resale during World War II and do not include stocks for the Strategic Stockpile.

TABLE 55.—Year-end stocks of titanium concentrates in the United States, 1941–54, in short tons ¹

Year	ILMENITE						TITANIUM SLAG			
	Mine stocks		Distributors' stocks ²		Consumers' stocks		Total		Consumers' stocks	
	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content
1941	28, 106	12, 087	12, 867	6, 032	311, 087	178, 258	352, 060	196, 377		
1942	11, 917	5, 142	11, 541	5, 371	149, 153	81, 735	172, 611	92, 248		
1943	3, 753	1, 771	5, 538	2, 492	118, 263	57, 786	127, 554	62, 049		
1944	1, 572	722	4, 542	2, 316	161, 572	72, 814	167, 686	75, 852		
1945	1, 570	774	6, 780	3, 254	264, 248	131, 732	272, 598	135, 760		
1946	1, 309	613	3, 919	2, 155	375, 998	195, 541	381, 226	198, 309		
1947	1, 706	776	5, 684	3, 126	446, 052	229, 128	453, 442	233, 030		
1948	3, 983	1, 800	4, 499	1, 809	522, 077	250, 559	530, 559	254, 168		
1949	16, 933	7, 569	158	92	681, 757	331, 483	698, 848	339, 144		
1950	32, 848	15, 216	169	101	649, 200	318, 894	682, 217	334, 211		
1951	57, 139	26, 925	692	415	619, 714	307, 211	877, 545	334, 551		
1952	54, 061	26, 347	958	574	610, 499	308, 046	665, 518	334, 967	16, 617	12, 101
1953	56, 738	24, 010	421	253	553, 116	284, 763	610, 275	309, 026	77, 926	55, 002
1954	71, 907	33, 298	715	425	562, 255	296, 339	634, 877	330, 062	81, 617	57, 355
1955										
1956										
1957										

Year	RUTILE						TITANIUM SLAG			
	Mine stocks		Distributors' stocks ²		Consumers' stocks		Government stocks ³		Total	
	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content	Gross weight	TiO ₂ content
1941	75	53	2, 387	2, 238	1, 144	1, 072	31	29	3, 637	3, 392
1942	54	50	1, 778	1, 653	1, 906	1, 775	2, 194	2, 062	5, 932	5, 540
1943	100	94	1, 012	941	1, 871	1, 745	3, 253	3, 058	6, 236	5, 838
1944	252	236	2, 532	2, 380	1, 720	1, 570	2, 500	2, 350	7, 004	6, 536
1945	594	558	4, 064	3, 739	1, 581	1, 464	3, 891	3, 658	10, 130	9, 419
1946	533	501	8, 488	7, 979	1, 896	1, 521	3, 891	3, 658	14, 808	13, 659
1947	3, 953	3, 687	8, 642	8, 123	1, 342	1, 232			13, 937	13, 042
1948	1, 500	1, 399	4, 218	3, 986	3, 493	3, 255			9, 211	8, 640
1949	2, 952	2, 750	2, 071	1, 967	3, 591	3, 355			8, 614	8, 072
1950	3, 780	3, 516	1, 799	1, 713	2, 750	2, 559			8, 329	7, 788
1951	55	51	539	511	5, 801	5, 491			6, 395	6, 053
1952	306	285	5, 279	5, 040	8, 153	7, 753			13, 738	13, 078
1953	655	611	4, 240	4, 060	11, 972	11, 374			16, 867	16, 045
1954	762	709	1, 934	1, 855	14, 178	13, 458			16, 874	16, 022
1955										
1956										
1957										

¹ Data not available before 1941.² Includes ilmenite and rutile content of mixed zirconium-titanium concentrates.³ Excludes stocks in Government Strategic Stockpile.

TARIFFS

Commodities included under Tariff Paragraph 89, as established in the Tariff Act of 1930, are "Titanium potassium oxalate, and all compounds and mixtures containing titanium." These were dutiable under the act at 30 percent ad valorem. The tariff on all items included under this paragraph was reduced to

15 percent ad valorem in negotiations with Benelux, at the General Agreement on Tariffs and Trade in Geneva, October 30, 1947. The reduction became effective January 1, 1948.

Ferrotitanium is one of the commodities included under Tariff Paragraph 302-m, dutiable under the act at 25 percent ad valorem. Under two bilateral trade agreements with Canada the tariff on these items was reduced to 15

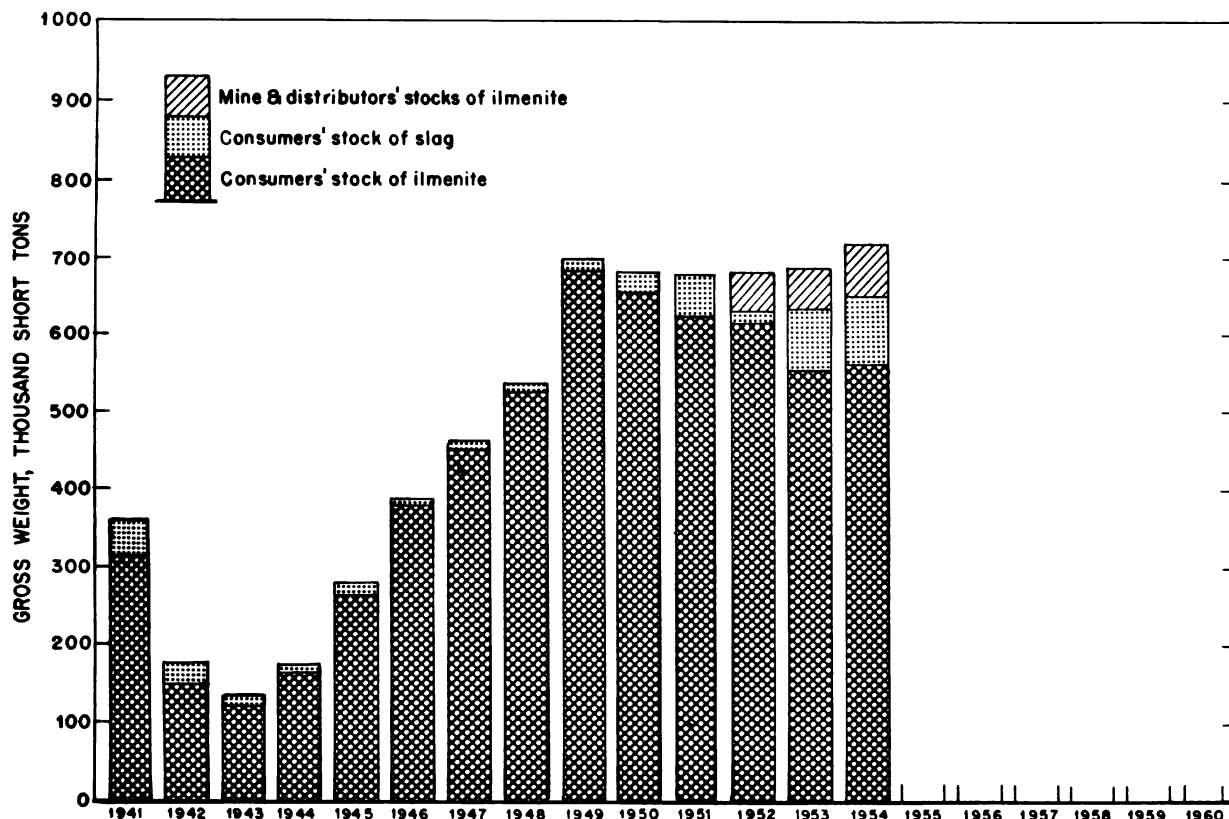


FIGURE 39. Stocks of Ilmenite Concentrate in the United States, 1941-54.

percent. The reduction became effective January 1, 1936, for ferrotitanium. At the General Agreement on Tariffs and Trade in Geneva the rate was reduced to 12½ percent ad valorem in negotiations with Canada. The reduction became effective January 1, 1948.

Titanium metal and alloys with aluminum, chromium, cobalt, copper, manganese, nickel, or silicon are included under Tariff Paragraph 302-n, dutiable under the act at 25 percent ad valorem. At the General Agreement on Tariffs and Trade in Torquay, the following rates were established:

1. Alloys of two or more of the following metals: Titanium, barium, boron, niobium (columbium), strontium, tantalum, thorium, vanadium, zirconium, calcium, and uranium: (a) Containing uranium but not containing niobium (columbium) or tantalum, 25 percent ad valorem; (b) other 12½ percent ad valorem.

2. Alloys of 1 or more of the above-named metals with 1 or more of the metals aluminum, chromium, cobalt, copper, manganese, nickel or silicon: (a) Con-

taining uranium, 25 percent ad valorem; (b) other, 20 percent ad valorem.

3. Titanium metal, 20 percent ad valorem.

Negotiations in this instance were with Canada. The new rates became effective June 6, 1951. Since World War II all imports of titanium alloys listed above were from Canada.

Titanium ores and concentrates, crude, or not advanced in value or condition, that were duty-free under the Tariff Act of 1922 are also duty-free under the Tariff Act of 1930 (Tariff Paragraph 1719) as "minerals, crude, or not advanced in value or condition by refining or grinding, or by other process of manufacture, n. s. p. f." The duty-free status of titanium ores and concentrates (except ilmenite and ilmenite sand) was bound in the GATT at Geneva, in negotiations with Brazil. The effective date of binding was January 1, 1948. Basic titanium slag, ground or unground, is also on the free list (Tariff Paragraph 1685).

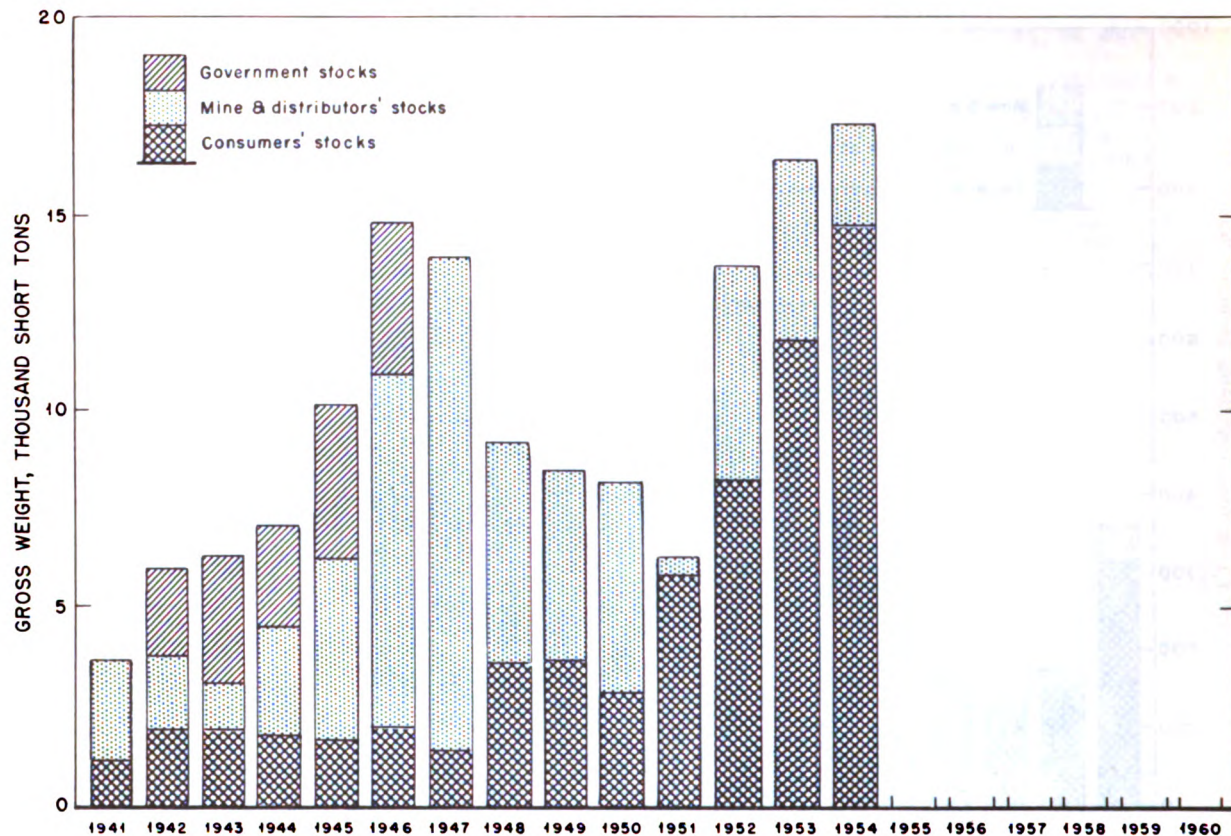


FIGURE 40. Stocks of Rutile Concentrate in the United States, 1941-54.

CHAPTER 9. MARKETING

ORES AND CONCENTRATES

Most of the domestic properties producing titanium ores and concentrates are owned by the major users of these minerals or their subsidiaries. A 10-year agreement between National Lead Co. and E. I. du Pont de Nemours & Co., Inc., for the sale of Tahawus ilmenite expired in October 1952. Since that time the major consumers have relied largely on ores and ilmenite concentrate from their own mines. A titanium slag averaging about 70 percent titanium dioxide is sold directly to consumers by the Quebec Iron & Titanium Corp. Slag is sold mainly to pigment manufacturers.

The Titanium Alloy Manufacturing Division of the National Lead Co. mines, concentrates, and sells both granular and milled rutile and ilmenite for the producers of coated welding rods. The company helped to develop the use of rutile in welding-rod coatings and supplies compounds for this purpose from its Florida mines. The Florida properties cannot satisfy all of the demand for rutile by the welding-rod manufacturers, and National Lead has therefore been forced to allocate its production. During the Korean War, when rutile was scarce, National Lead offered either to mill rutile bought by its customers from foreign sources for \$22.50 per ton or to supply rutile from foreign sources and charge the customer the price of the ore plus \$22.50 per ton milling charge. This offer was to accommodate consumers who had no milling facilities of their own.

In Australia, the chief foreign source of rutile

supply for domestic users, only one of the producing mines has its own sales department. The remaining Australian production is handled by mineral brokers, who are usually backed by London firms. The larger brokers act as true brokers in that they usually place orders with the mines for only as much rutile as their customers require. Some smaller brokers, however, place orders for much larger quantities than they require, in anticipation of price increases. Contracts between brokers and mine owners are usually on a fairly long term basis, being as much as 3 to 5 years in advance. When the price of rutile is low, purchasers must also buy a certain percentage of zircon with the rutile. When the price of rutile is high, purchasers are not required to take any zircon with their orders.

Indian ilmenite is sold partly through brokers and partly by direct contact between purchasers and mines. The larger importers in this country make contracts with the mines directly, while smaller purchasers buy their ilmenite through brokers. Contracts are usually on a year-to-year basis.

Ilmenite, rutile, leucoxene, titanium slag, and various mixtures thereof are marketed for use in a variety of end products. The differences in desirable characteristics of titaniferous raw materials, as used in different end products, divide the market into a number of groups. The nature of these markets is best illustrated by listing the desirable properties for ores and concentrates for use in manufacturing titanium tetrachloride, pigments, alloys and carbides, and welding-rod coatings. Tables 56 and 57

TABLE 56.—Typical chemical composition of some ilmenite concentrates

Composition	Australia		Brazil	Canada		India			Malaya	Norway	United States		
	Southeast Queensland	Cheyne Beach (Western Australia)		Q. I. T. slag	St. Urbain	Chavara	Manavalakurichi	Quilon	"Amang"	Stavanger	Florida	Piney River, Va.	Tahawus, N. Y.
TiO ₂	48.53	52.12	48.3	70.8	41.95	60.03	54.0	60.4	51-55	44.40	57.50	44.00	44.5
Fe ₂ O ₃	10-12	16.15	16.6		18.64	24.77	17.0	24.9	8-18	12.44	24.60	13.90	5.2
FeO.....	31-33	29.04	32.4	6.8	29.30	9.67	23.0	8.7	26-32	34.00	12.30	36.80	39.1
Al ₂ O ₃			.3	6.3	2.70			1.30			1.24	.49	3.0
MnO.....		1.61	.6	.24	10	.47	.40	.44	2.5-4.5	.37		.58	.3
CaO.....			.1	1.1	.40			.05				.08	1.0
Na ₂ O.....					.01						.04		
K ₂ O.....													
MgO.....		.28	.1		4.30			.73		3.55		.63	2.0
Cr ₂ O ₃	5-5.2	.04	.5	.29	.20	.08	.05	.08	.03-10	.01		.09	.15
V ₂ O ₅		.14	.06	.48	.18	.20	.18	.05	.03-10	.18		.22	.10
ZrO ₂			.1			.76	.83						
S.....				.20							.01		.10
P ₂ O ₅						.19	.22	.2	.1-2	.02	.03	.08	.01
SiO ₂		.18	1.4	6.1	2.56	.71	1.18	.76	2.0	3.79	2.14	1.40	3.0
H ₂ O.....						1.30	.3						

list the chemical composition of some ilmenite and rutile ores and illustrate why some ores are preferred over others.

TABLE 57.—*Typical chemical composition of some rutile concentrates*

	Florida	Travan- core, India	French Cam- eroons (pebble)	New South Wales, Australia	Queens- land, Australia
TiO ₂	93.64	96.42	97.51	95.74	98.77
Fe ₂ O ₃	2.56	1.14	.64	.40	
FeO.....					.55
Al ₂ O ₃	.46			1.25	.14
MnO ₂	.05		.08		
CaO.....	.02		.16	.04	
Na ₂ O, K ₂ O.....	.01	.60	.30	.20	
MgO.....	.06		.29	.04	
Cr ₂ O ₃	.14	.30	.10	.66	.16
V ₂ O ₅	.29				
S.....		.80		.03	
P ₂ O ₅	.10	.04	.08	.12	
SiO ₂	1.02	.43	.25	.69	.23
ZrO ₂	1.46				
H ₂ O.....	.12	.28	.14	.17	

PROPERTIES FOR TITANIUM TETRACHLORIDE

Titanium tetrachloride is manufactured by passing chlorine through a mixture of finely ground ore and a carbon reductant, such as coal or coke. Production of titanium metal excepted, the major uses to which commercial titanium tetrachloride is put do not require purification. Iron, vanadium, and similar impurities may be precipitated from this product by treating with hydrogen sulfide at 212° F., and the majority of impurities can be removed by fractional distillation. Some complex chlorides of silicon and some chlorides of vanadium require special means of separation.

The major requirements for a titanium mineral to be used in producing titanium tetrachloride may be summarized as follows:

1. Ease in grinding. While not eliminating any commercial sources, this could place slag and some massive ores at an economic disadvantage. Grinding of slag might present dusting problems.
2. Low silicon content. While not actually eliminating any commercial sources, it does place a burden on the user.
3. Low iron-titanium dioxide ratio. This places many mineral deposits in the submarginal class. Rutile is, for this reason, especially desirable, since separation of large quantities of ferric chloride (obtained by chlorinating minerals with high iron content) poses a number of engineering problems. Ferric chloride does not at present find a large market or command a satisfactory price. Other elements that consume chlorine, such as silicon, aluminum, magnesium, and calcium, are also undesirable in the raw material because the added chlorine requirements increase the price of the finished product.
4. Low calcium and magnesium. Calcium and magnesium, besides being chlorine consumers, form a pasty mass in the chlorination furnace and give a great deal of difficulty. In the fluid (moving-bed) furnace these elements may sometimes stop the reaction. Sorel slag contains calcium and magnesium, and this is one of the reasons that slag has not as yet been commercially accepted as a substitute for rutile in the production of titanium tetrachloride.

PROPERTIES FOR PIGMENTS

Most pigments produced are made by the sulfate process, in which the titaniferous material is digested with sulfuric acid. Minerals used for manufacturing pigments by the sulfate process must therefore be soluble in sulfuric acid. Rutile and leucoxene are insoluble in sulfuric acid and not usable for sulfate titanium-pigment manufacture. However, one manufacturer makes pigments from titanium tetrachloride and hence uses a mixture of ilmenite, rutile, and leucoxene as a raw material.

The sulfuric acid used in dissolving the titanium also dissolves the iron present in the titanium mineral, and the ferric iron is reduced to ferrous iron to permit removal by recrystallization of ferrous sulfate. Reduction is accomplished by adding scrap iron, which goes into solution, increasing the iron content of the solution above the level directly obtained from the mineral.

The amount of titanium sulfate, ferrous sulfate, and combinations of the two that may be held in sulfuric-acid solution is limited. There is also a minimum concentration of titanium sulfate below which the titanium is unstable and will separate, ruining the solution for pigment manufacture. With a limit to the total titanium and iron solubility and approximately equal recovery of the two metals from minerals to solution, the level of titanium concentration is determined by the iron present in the mineral.

Some portion of all commercial titanium minerals is insoluble in sulfuric acid. This insoluble gangue must be completely separated from the solution of titanium sulfate, so as not to discolor the white pigment precipitated from the solution. The titanium sulfate that wets the gangue must be separated with a minimum of acid washing to avoid loss of valuable titanium. A necessary characteristic of the titanium mineral is that it be low in gangue content and that the physical characteristics of the gangue minerals be such that they separate readily from the titanium-iron sulfate solutions.

The presence of soluble salts of chromium, vanadium, or other elements may make a mineral unsuitable for pigment production. These discolor the pigment and make it unsalable.

The major requirements for a titanium mineral to be used in producing titanium pigments by the sulfate process may be summarized as follows:

1. Solubility in sulfuric acid. This eliminates rutile and leucoxene.
2. Low iron-titanium dioxide ratio. This eliminates some Canadian ores (but not the Sorel slag) and certain sands, such as those of New Zealand, and places many minerals in a submarginal class.

3. **Low gangue content.** While not actually eliminating any commercial sources, ore with high gangue content is burdensome to use.

4. **Low content of chromium, vanadium, and other soluble impurities.** The high chromium content of Australian ilmenite makes it unsuitable for pigment use.

PROPERTIES FOR ALLOYS

High-carbon ferroalloys are produced in an electric furnace from a mixture of ilmenite and steel scrap. Medium-carbon ferroalloys are made in the same fashion, but some rutile is used, in addition to the ilmenite. Rutile is currently used for producing low-carbon ferroalloys. Pigment-grade titanium dioxide could supplant rutile in these uses, but it is estimated that the substitution would roughly double the titaniferous raw material cost, which represents over 25 percent of the total. Hence, this would result in a minimum increase in total cost of 25 percent. Rutile is an essential ingredient for aluminum and nickel master alloys, although the quantity used for this purpose is small.

PROPERTIES FOR WELDING-ROD COATINGS

In general, rutile, ilmenite, or other natural minerals, such as calcium-titanium silicate and calcium titanate, are employed as a source of the oxide because of low cost; but there are some applications that demand an arc stabilizer of a fineness attainable only by using the chemically precipitated oxide. Considerable quantities of manufactured potassium and sodium titanates are also used. Of the impurities normally present in rutile, sulfur is likely to give the most trouble, although measurements have shown that 1 percent of the sulfur contained in the original composition is lost in the arcing process. Natural calcium-titanium silicate furnishes an economical source of titanium dioxide, and preliminary tests indicate that it will give a quiet arc and a brittle and easily fusible slag, although rutile remains the principal raw material for this purpose.

Each manufacturer develops his own particular formula for flux coatings, which is seldom made available to the industry. Specifications for titanium minerals to be used in welding-rod coatings are therefore not readily available.

TITANIUM SPONGE

Since 1948 the outstanding characteristic of the market has been dynamic change, with emphasis on improving the Kroll process and cooperation with fabricators in developing techniques for melting, rolling, forging, welding, and forming the metal. In 1954 the two principal producers of commercially pure sponge

were E. I. du Pont de Nemours & Co., Inc., and Titanium Metals Corp. of America.

Sponge from TMCA was melted in TMCA facilities; but the ingots were processed into mill products by Allegheny Ludlum Steel Corp., which charged TMCA on a fee-for-service basis. Allegheny Ludlum does not buy or sell titanium sponge, scrap, or fabricated metal.

Du Pont's market for titanium sponge in 1954 included Rem-Cru Titanium, Inc., Mallory-Sharon Titanium Corp., and Republic Steel Corp. A small amount of offgrade material was consumed as an alloying ingredient by a number of steel producers. Du Pont worked closely with its customers, making available its technical knowledge and the services of specialists and gearing specifications to the requirements of titanium fabricators.

In early 1955 sponge that was not sold to semifabricators was sold to the Government revolving stockpile.

MILL PRODUCTS

The uses of fabricated titanium metal remain in the development stage. Specific designing for titanium is reported to be the exception rather than the general rule. A market for the product, other than for research purposes, has appeared mainly in the aircraft and chemical industries. One leading producer reports 250 customers, but it does 90 percent of its business with 20 companies. With increasing output, titanium fabrication and use could easily spread to several thousand companies.

Marketing methods for fabricated titanium products are similar to those for titanium sponge, in that the emphasis is on fundamental research and on close cooperation between producers and their customers. This is evidenced by the large volume of handbook and other information published by producers, which frequently contains data compiled in the laboratories of consumers and other outside interest groups. One seller reported spending \$300,000 in 2 years on technical assistance to forging companies. During the same period this company cooperated with customers in the development of new alloys, utilization of scrap, and other technical problems.

Outstanding marketing problems are the recycling and utilization of scrap, since the amount of scrap reclaimed will greatly affect the price of titanium. Such is the case with similar materials (for example, stainless steel), where the price of the product would be considerably greater without utilization of all grades of scrap in massive quantities. In 1955 scrap began to have a more definite market as the melters bought commercially pure and some alloy scrap from their customers.

PIGMENTS

The basic uses of titanium pigments by the paint and allied industries have remained relatively stable for the past two decades. Some producers of titanium pigments market paints containing the product and, in addition, sell pigments to paint manufacturers. Sherwin-Williams and others, for example, purchase titanium pigments from Du Pont, National Lead, and others and market their paints in competition with those of Du Pont, Glidden, and National Lead.

Titanium pigments are purchased for use in paints, lacquers, paper, floor coverings, rubber, coated fabrics, and a variety of other products. Replacement of titanium dioxide by other pigments is considered to be technically undesirable, hence, market demand is relatively unresponsive to changes in the price of titanium pigments, or, vice versa, to prices of potential substitutes.

Potential buyers are supplied with detailed information regarding particle size, covering power, effect on vehicle, etc. These data have no generally accepted applicability in determining the quality of the product and must be interpreted by each user in terms of his own needs.

ALLOYS

Titanium master alloys are sold in tonnage quantities to the iron and steel industries. Because of their relative freedom from impurities and controlled composition, they are used in preference to the natural ores as a medium for adding titanium, which acts as a deoxidizer, grain refiner, and alloying ingredient.

Producers of pig aluminum manufacture titanium-alloying ingredients within their own plants but do not market them. A few companies also supply a 5-percent titanium master alloy, as well as potassium-titanium fluoride to the aluminum melters. A small number of steel manufacturers produce ferrotitanium for their own use, but the majority meet their present needs from firms specializing in its manufacture. The Titanium Alloy Manufacturing Division, National Lead Co., has numerous customers for ferroalloys, 10 of which (including U. S. Steel, Bethlehem Steel, Inland

Steel, and Republic Steel) take roughly 50 percent of the product.

The sales staff of the ferroalloy producers is composed of technical salesmen who are usually metallurgical engineers. The salesmen know how the mills of the consumer operate and are in a position to recommend specific ferroalloys or practices to solve customer problems. The ferroalloy producers also have their own research laboratories whose purpose is to develop new alloys, to determine the effect of present alloys on steel, and to function as service laboratories for customers. Particular emphasis is placed upon developing new alloys to meet the constant competition of other producers.

The demand for ferroalloys is closely correlated with the sales of steel. In recent years the demand for low-carbon-grade ferrotitanium, used chiefly in producing high-temperature steel alloys and A321 stainless steel, has increased relatively more than for the other grades. Demand for the high-carbon grades is felt to be relatively elastic with respect to price. The demand for medium-carbon ferrotitanium was negligible in 1954, and there were few customers. The ferrotitanium industry is especially hard hit by slack periods in the production of steel. The steel producers are then able to take more time to make a heat, and when this occurs less ferrotitanium is required per heat. Also, the steelmakers attempt to cut costs in slack periods and therefore use as little ferroalloys as possible.

WELDING-ROD COATINGS

Uniform specifications for welding rods and coatings are quite rare. Marketing the product involves close cooperation between producers and their customers. In placing orders, purchasers often describe a specific welding problem and ask for technical information and a bid for supplying the appropriate type of rod. The business is based, to a large extent, upon service of this type. Suppliers of products used in compounding coatings for mild and alloy-steel welding rod do prepare specifications and present general information on welding-rod coatings based on past experience in the field. Their business depends upon technical service and cooperation with manufacturers and users of the coated rods.

CHAPTER 10. PRICES

ORES AND CONCENTRATES

Table 58 shows the nominal prices and specified titanium dioxide content for ilmenite and rutile from 1928 through 1954. For the most part, these quotations were f. o. b. Atlantic seaboard.

The outstanding aspect of these prices before World War II was their inflexibility in response to changing economic conditions (that is, the depression of the 30's). Maximum prices for ilmenite and rutile were maintained by the Office of Price Administration from April 28, 1942, to July 26, 1946; and for rutile, by the Office of Price Stabilization from January 26, 1951, to January 18, 1952.

Owing to greatly increased demand and lack of shipments from India, ilmenite prices rose

TABLE 58.—Year-end prices of ilmenite and rutile, United States, 1928–55¹

Year	Ilmenite		Rutile	
	TiO ₂ content, percent	Dollars per long ton	TiO ₂ content, percent	Cents per pound
1928	50	8.48-9.82		9.50
1929				
1930				
1931	45-52	8.93-10.71	94	10.00
1932	32-35	6.25-7.14	94	10.00
1933	40-45	8.33-10.71		
1934	45-52	8.93-10.71		
1935		10.71		
1936			(⁴) 94	(⁴) 10.00
1937				
1938	45-55	10-12	94	10.00
1939	45-55	10-12	88-90	2.75
1940	45-55	10-12	94	10.00
1941	50-60	18-20	88-90	3.75
1942	60	28-30	94	8-10
1943	60	28-30	88-90	4.75
1944	60	28-30	94 (min.)	8-10
1945	60	28-30	94 (min.)	8-10
1946	57-60	19-20	94 (min.)	8-10
1947	57-60	19-20	94 (min.)	8-10
1948	56-59	18-20	94 (min.)	6-8
1949	56-59	14-16	94 (min.)	4-5
1950	56-59	14-16	94 (min.)	3.5-4.5
1951	56-59	16-18	94 (min.)	5.25-6.25
1952	56-59	18-20	94 (min.)	7-8.50
1953	59.5	18-20	94 (min.)	5-6
1954	59.5	18-20	94 (min.)	6.75-7
1955	59.5	20	94 (min.)	10-15
1956				
1957				

¹ Prices are nominal quotations, per gross ton, f. o. b. Atlantic seaboard except where otherwise designated. Data not available before 1928.

² Carlots.

³ Delivered at Niagara Falls, N. Y.

⁴ Lower grade, less than 5 cents per pound.

roughly 150 percent between 1939 and 1942. The price of ilmenite remained on this plateau until 1946, in spite of resumption of imports from India in 1944 and opening of new mines in New York and Florida. Ilmenite prices today are higher than prewar prices; however, present minimum specifications are higher than those in the prewar period.

From 1948–54 the price of rutile, 94 percent titanium dioxide, was lower than during the prewar period. This probably reflects the increased supply from Australia, as mines were developed there rapidly after World War II. Owing to the increased demand for rutile, the nominal price was raised several times in 1955, so that by June it was selling for 9 to 10 cents per pound.

Prices for domestic rutile differed somewhat from those for imported rutile. In December 1954 the Oil, Paint and Drug Reporter published the following prices for rutile concentrate, Metallurgical Grade.

Natural granular, bags, carlots, per short ton,	
f. o. b. Jacksonville, Fla.	\$120.00
Niagara Falls, N. Y., carlots	137.50
5-ton lots, same basis	142.50
1-ton lots, same basis	147.50
(Milled, \$7.50 per ton higher.)	

The Quebec Iron & Titanium Corp. produces and markets two grades of titanium slag: Pigment Grade and Experimental High Grade. In the early part of 1955 the Pigment Grade, averaging about 70 percent titanium dioxide, sold for \$36 per long ton plus 28 cents for each half point over 70 percent TiO₂. The Experimental High-Grade slag, containing 78 to 80 percent titanium dioxide, was quoted at \$70 per long ton. The maximum titanium dioxide content of the Pigment Grade was 72 percent.

In general, titanium ores and concentrates are priced according to their titanium dioxide content. In marketing rutile for the manufacture of titanium tetrachloride, it is not the practice to assign penalties for undesirable minerals contained in the concentrate as long, as the titanium dioxide content exceeds 94 percent.

TITANIUM SPONGE

From 1948, when commercial production was first announced by Du Pont, until 1954 the price of titanium sponge was \$5 per pound in greater-than-100-pound lots and \$7.50 per

pound in less-than-100-pound lots. On April 1, 1954, the price was reduced to \$4.72 a pound for Grade A-1, containing 0.30 percent iron, and \$4.46 a pound for Grade A-2, containing 0.50 percent iron. Further reductions were effected on December 1, 1954, when a price of \$4.50 for Grade A-1 and a price of \$4 for Grade A-2 went into effect. The third price reduction for titanium metal took place on April 1, 1955, after which the price for titanium-sponge metal was quoted as \$3.95 per pound for Grade A-1 and \$3.50 per pound for Grade A-2. A \$1 differential applies to quantities less than 100 pounds. Growing efficiency and sustained capacity operations were reasons given by the titanium industry for its series of price reductions.

MILL PRODUCTS

The Titanium Metals Corp. of America published the first price list for titanium mill products on December 1, 1950. These base prices remained unchanged until February 1954. The company reports that price and cost schedules are reviewed approximately every 6 months for possible changes in the price list. The base prices listed by TMCA from 1950 until 1954 follow:

	<i>Per pound</i>
Sheet.....	\$15. 00
Strip.....	15. 00
Plate.....	12. 00
Wire.....	10. 00
Forging billets.....	6. 00
Bars.....	6. 00

Extras for length, width, gage, finish, etc., had to be added to these base prices to calculate the cost to consumers for the mill product. In many instances extras increased the price 50 to 75 percent of the base price.

Titanium Metals Corp. of America and Rem-Cru Titanium, Inc., announced in 1954 price reductions on titanium mill-product extras that ranged from 8 to 14 percent. TMCA reduced its prices on titanium sheet and plate extras on February 11, 1954, and on titanium-strip extras on April 26, 1954. Rem-Cru cut its prices for bar and billet extras on February 19, 1954. Price quotations for titanium-mill products (base price), f. o. b. producing mill, were published at the end of 1954 in Steel magazine as follows:

	<i>Per pound</i>
Sheet.....	\$15. 00
Strip.....	15. 00
Plate.....	12. 00
Wire.....	11. 00
Forging billets.....	9. 00
Bars.....	9. 00

TABLE 59.—Base prices per pound of mill product, effective April 1, 1955

Manufacturer	Grade designation	Sheet	Strip	Plate	Wire	Bar	Billet
Mallory-Sharon Titanium Corp.	MST Grade III ¹	\$14. 50	\$14. 50	\$12. 00		\$8. 75	\$8. 75
	MST Grade III ²	14. 00	14. 00	11. 50		8. 50	8. 50
	MST Grade III ³	14. 00	14. 00	11. 50		8. 50	8. 50
	MST 3Al-5Cr.....			12. 50		8. 50	8. 50
	MST 4Al-4Mn.....			12. 50		8. 50	8. 50
	MST 8Mn.....	16. 50		12. 50			
	MST 6 Al-4V.....	16. 50		12. 75		8. 75	8. 75
Rem-Cru Titanium, Inc.	A-40.....	14. 50	14. 50	12. 00	\$11. 00	8. 75	8. 75
	A-55.....	14. 00	14. 00	11. 50	10. 50	8. 50	8. 50
	A-70.....	14. 00	14. 00	11. 50	10. 50	8. 50	8. 50
	C-130AM.....			12. 50	12. 50	8. 50	8. 50
	A-110AT.....	17. 00		12. 75	12. 50	8. 75	8. 75
	C-110M.....	16. 50		12. 50			
	C-120AM.....					8. 75	8. 75
	C-120AV.....	16. 50		12. 75	12. 50	8. 75	8. 75
Republic Steel Corp.	RS-40.....	14. 50		12. 00	11. 00	8. 75	8. 75
	RS-55.....	14. 00		11. 50	10. 50	8. 50	8. 50
	RS-70.....	14. 00		11. 50	10. 50	8. 50	8. 50
	RS-70-A.....	14. 00		11. 50	10. 50	8. 50	8. 50
	RS-110-A.....	16. 50		12. 50			
	RS-120.....				12. 50	8. 50	8. 50
	RS-130.....				12. 50	8. 50	8. 50
Titanium Metals Corp. of America.	Ti-55A.....	14. 50	14. 50	12. 00	11. 00	8. 75	8. 75
	Ti-65A.....	14. 00	14. 00	11. 50	10. 50	8. 50	8. 50
	Ti-75A.....	14. 00	14. 00	11. 50	10. 50	8. 50	8. 50
	Ti-100A.....	14. 00	14. 00	11. 50	10. 50	8. 50	8. 50
	Ti-140A.....	16. 50	16. 50	12. 50	12. 50	8. 50	8. 50
	Ti-155A.....			12. 50		8. 50	8. 50
	Ti-6Al-4V.....	16. 50	16. 50	12. 75	12. 50	8. 75	8. 75

¹ 50,000 typical yield.

² 65,000 typical yield.

³ 80,000 typical yield.

Although the base price apparently rose on some mill products, the cost of extras decreased, resulting in a lowered cost to the consumer.

Further reductions in the base prices of mill products were effected on April 1, 1955, by all the producers. Base prices on sheet and strip were reduced \$1.00, while prices on plate, wire, bar, and billets were reduced \$0.50. All of the companies listed approximately the same prices for similar products. Base prices for mill products, effective April 1, 1955, are shown in table 59.

To get a true picture of the final price to the consumer, it is necessary also to consider the various extras that are added to the base price. Comparison of the price schedules for the various companies producing titanium mill products indicates that all of them charge the same price for extras; therefore, it is possible to list a typical schedule of extras for the four producers. Only the extras that apply to sheet will be discussed here. For information on extras applying to the other mill products, one may consult the sales literature of any of the semifabricators.

SHEET EXTRAS

Titanium sheet is produced in 24- to 36-inch widths, inclusive, and in 72- to 96-inch lengths, inclusive. The shortest dimension is always considered as width and should be specified in even inches or fractions thereof.

The National Aircraft Standards Committee has established a set of standard thicknesses for sheet metals used on military aircraft, and manufacturers have recommended that titanium sheets be ordered in the thicknesses shown below. The preferred thicknesses are in italics.

Standard thickness (inch)

<i>0.016</i>	<i>0.026</i>	<i>0.036</i>	<i>0.046</i>	<i>0.056</i>	<i>0.066</i>	<i>0.076</i>	<i>0.086</i>	<i>0.096</i>	<i>0.106</i>	<i>0.116</i>	<i>0.126</i>	<i>0.136</i>	<i>0.146</i>	<i>0.156</i>	<i>0.166</i>	<i>0.176</i>	<i>0.186</i>	<i>0.196</i>	<i>0.206</i>	<i>0.216</i>	<i>0.226</i>	<i>0.236</i>	<i>0.246</i>	<i>0.256</i>	<i>0.266</i>	<i>0.276</i>	<i>0.286</i>	<i>0.296</i>	<i>0.306</i>	<i>0.316</i>	<i>0.326</i>	<i>0.336</i>	<i>0.346</i>	<i>0.356</i>	<i>0.366</i>	<i>0.376</i>	<i>0.386</i>	<i>0.396</i>	<i>0.406</i>	<i>0.416</i>	<i>0.426</i>	<i>0.436</i>	<i>0.446</i>	<i>0.456</i>	<i>0.466</i>	<i>0.476</i>	<i>0.486</i>	<i>0.496</i>	<i>0.506</i>	<i>0.516</i>	<i>0.526</i>	<i>0.536</i>	<i>0.546</i>	<i>0.556</i>	<i>0.566</i>	<i>0.576</i>	<i>0.586</i>	<i>0.596</i>	<i>0.606</i>	<i>0.616</i>	<i>0.626</i>	<i>0.636</i>	<i>0.646</i>	<i>0.656</i>	<i>0.666</i>	<i>0.676</i>	<i>0.686</i>	<i>0.696</i>	<i>0.706</i>	<i>0.716</i>	<i>0.726</i>	<i>0.736</i>	<i>0.746</i>	<i>0.756</i>	<i>0.766</i>	<i>0.776</i>	<i>0.786</i>	<i>0.796</i>	<i>0.806</i>	<i>0.816</i>	<i>0.826</i>	<i>0.836</i>	<i>0.846</i>	<i>0.856</i>	<i>0.866</i>	<i>0.876</i>	<i>0.886</i>	<i>0.896</i>	<i>0.906</i>	<i>0.916</i>	<i>0.926</i>	<i>0.936</i>	<i>0.946</i>	<i>0.956</i>	<i>0.966</i>	<i>0.976</i>	<i>0.986</i>	<i>0.996</i>	<i>1.006</i>	<i>1.016</i>	<i>1.026</i>	<i>1.036</i>	<i>1.046</i>	<i>1.056</i>	<i>1.066</i>	<i>1.076</i>	<i>1.086</i>	<i>1.096</i>	<i>1.106</i>	<i>1.116</i>	<i>1.126</i>	<i>1.136</i>	<i>1.146</i>	<i>1.156</i>	<i>1.166</i>	<i>1.176</i>	<i>1.186</i>	<i>1.196</i>	<i>1.206</i>	<i>1.216</i>	<i>1.226</i>	<i>1.236</i>	<i>1.246</i>	<i>1.256</i>	<i>1.266</i>	<i>1.276</i>	<i>1.286</i>	<i>1.296</i>	<i>1.306</i>	<i>1.316</i>	<i>1.326</i>	<i>1.336</i>	<i>1.346</i>	<i>1.356</i>	<i>1.366</i>	<i>1.376</i>	<i>1.386</i>	<i>1.396</i>	<i>1.406</i>	<i>1.416</i>	<i>1.426</i>	<i>1.436</i>	<i>1.446</i>	<i>1.456</i>	<i>1.466</i>	<i>1.476</i>	<i>1.486</i>	<i>1.496</i>	<i>1.506</i>	<i>1.516</i>	<i>1.526</i>	<i>1.536</i>	<i>1.546</i>	<i>1.556</i>	<i>1.566</i>	<i>1.576</i>	<i>1.586</i>	<i>1.596</i>	<i>1.606</i>	<i>1.616</i>	<i>1.626</i>	<i>1.636</i>	<i>1.646</i>	<i>1.656</i>	<i>1.666</i>	<i>1.676</i>	<i>1.686</i>	<i>1.696</i>	<i>1.706</i>	<i>1.716</i>	<i>1.726</i>	<i>1.736</i>	<i>1.746</i>	<i>1.756</i>	<i>1.766</i>	<i>1.776</i>	<i>1.786</i>	<i>1.796</i>	<i>1.806</i>	<i>1.816</i>	<i>1.826</i>	<i>1.836</i>	<i>1.846</i>	<i>1.856</i>	<i>1.866</i>	<i>1.876</i>	<i>1.886</i>	<i>1.896</i>	<i>1.906</i>	<i>1.916</i>	<i>1.926</i>	<i>1.936</i>	<i>1.946</i>	<i>1.956</i>	<i>1.966</i>	<i>1.976</i>	<i>1.986</i>	<i>1.996</i>	<i>2.006</i>	<i>2.016</i>	<i>2.026</i>	<i>2.036</i>	<i>2.046</i>	<i>2.056</i>	<i>2.066</i>	<i>2.076</i>	<i>2.086</i>	<i>2.096</i>	<i>2.106</i>	<i>2.116</i>	<i>2.126</i>	<i>2.136</i>	<i>2.146</i>	<i>2.156</i>	<i>2.166</i>	<i>2.176</i>	<i>2.186</i>	<i>2.196</i>	<i>2.206</i>	<i>2.216</i>	<i>2.226</i>	<i>2.236</i>	<i>2.246</i>	<i>2.256</i>	<i>2.266</i>	<i>2.276</i>	<i>2.286</i>	<i>2.296</i>	<i>2.306</i>	<i>2.316</i>	<i>2.326</i>	<i>2.336</i>	<i>2.346</i>	<i>2.356</i>	<i>2.366</i>	<i>2.376</i>	<i>2.386</i>	<i>2.396</i>	<i>2.406</i>	<i>2.416</i>	<i>2.426</i>	<i>2.436</i>	<i>2.446</i>	<i>2.456</i>	<i>2.466</i>	<i>2.476</i>	<i>2.486</i>	<i>2.496</i>	<i>2.506</i>	<i>2.516</i>	<i>2.526</i>	<i>2.536</i>	<i>2.546</i>	<i>2.556</i>	<i>2.566</i>	<i>2.576</i>	<i>2.586</i>	<i>2.596</i>	<i>2.606</i>	<i>2.616</i>	<i>2.626</i>	<i>2.636</i>	<i>2.646</i>	<i>2.656</i>	<i>2.666</i>	<i>2.676</i>	<i>2.686</i>	<i>2.696</i>	<i>2.706</i>	<i>2.716</i>	<i>2.726</i>	<i>2.736</i>	<i>2.746</i>	<i>2.756</i>	<i>2.766</i>	<i>2.776</i>	<i>2.786</i>	<i>2.796</i>	<i>2.806</i>	<i>2.816</i>	<i>2.826</i>	<i>2.836</i>	<i>2.846</i>	<i>2.856</i>	<i>2.866</i>	<i>2.876</i>	<i>2.886</i>	<i>2.896</i>	<i>2.906</i>	<i>2.916</i>	<i>2.926</i>	<i>2.936</i>	<i>2.946</i>	<i>2.956</i>	<i>2.966</i>	<i>2.976</i>	<i>2.986</i>	<i>2.996</i>	<i>3.006</i>	<i>3.016</i>	<i>3.026</i>	<i>3.036</i>	<i>3.046</i>	<i>3.056</i>	<i>3.066</i>	<i>3.076</i>	<i>3.086</i>	<i>3.096</i>	<i>3.106</i>	<i>3.116</i>	<i>3.126</i>	<i>3.136</i>	<i>3.146</i>	<i>3.156</i>	<i>3.166</i>	<i>3.176</i>	<i>3.186</i>	<i>3.196</i>	<i>3.206</i>	<i>3.216</i>	<i>3.226</i>	<i>3.236</i>	<i>3.246</i>	<i>3.256</i>	<i>3.266</i>	<i>3.276</i>	<i>3.286</i>	<i>3.296</i>	<i>3.306</i>	<i>3.316</i>	<i>3.326</i>	<i>3.336</i>	<i>3.346</i>	<i>3.356</i>	<i>3.366</i>	<i>3.376</i>	<i>3.386</i>	<i>3.396</i>	<i>3.406</i>	<i>3.416</i>	<i>3.426</i>	<i>3.436</i>	<i>3.446</i>	<i>3.456</i>	<i>3.466</i>	<i>3.476</i>	<i>3.486</i>	<i>3.496</i>	<i>3.506</i>	<i>3.516</i>	<i>3.526</i>	<i>3.536</i>	<i>3.546</i>	<i>3.556</i>	<i>3.566</i>	<i>3.576</i>	<i>3.586</i>	<i>3.596</i>	<i>3.606</i>	<i>3.616</i>	<i>3.626</i>	<i>3.636</i>	<i>3.646</i>	<i>3.656</i>	<i>3.666</i>	<i>3.676</i>	<i>3.686</i>	<i>3.696</i>	<i>3.706</i>	<i>3.716</i>	<i>3.726</i>	<i>3.736</i>	<i>3.746</i>	<i>3.756</i>	<i>3.766</i>	<i>3.776</i>	<i>3.786</i>	<i>3.796</i>	<i>3.806</i>	<i>3.816</i>	<i>3.826</i>	<i>3.836</i>	<i>3.846</i>	<i>3.856</i>	<i>3.866</i>	<i>3.876</i>	<i>3.886</i>	<i>3.896</i>	<i>3.906</i>	<i>3.916</i>	<i>3.926</i>	<i>3.936</i>	<i>3.946</i>	<i>3.956</i>	<i>3.966</i>	<i>3.976</i>	<i>3.986</i>	<i>3.996</i>	<i>4.006</i>	<i>4.016</i>	<i>4.026</i>	<i>4.036</i>	<i>4.046</i>	<i>4.056</i>	<i>4.066</i>	<i>4.076</i>	<i>4.086</i>	<i>4.096</i>	<i>4.106</i>	<i>4.116</i>	<i>4.126</i>	<i>4.136</i>	<i>4.146</i>	<i>4.156</i>	<i>4.166</i>	<i>4.176</i>	<i>4.186</i>	<i>4.196</i>	<i>4.206</i>	<i>4.216</i>	<i>4.226</i>	<i>4.236</i>	<i>4.246</i>	<i>4.256</i>	<i>4.266</i>	<i>4.276</i>	<i>4.286</i>	<i>4.296</i>	<i>4.306</i>	<i>4.316</i>	<i>4.326</i>	<i>4.336</i>	<i>4.346</i>	<i>4.356</i>	<i>4.366</i>	<i>4.376</i>	<i>4.386</i>	<i>4.396</i>	<i>4.406</i>	<i>4.416</i>	<i>4.426</i>	<i>4.436</i>	<i>4.446</i>	<i>4.456</i>	<i>4.466</i>	<i>4.476</i>	<i>4.486</i>	<i>4.496</i>	<i>4.506</i>	<i>4.516</i>	<i>4.526</i>	<i>4.536</i>	<i>4.546</i>	<i>4.556</i>	<i>4.566</i>	<i>4.576</i>	<i>4.586</i>	<i>4.596</i>	<i>4.606</i>	<i>4.616</i>	<i>4.626</i>	<i>4.636</i>	<i>4.646</i>	<i>4.656</i>	<i>4.666</i>	<i>4.676</i>	<i>4.686</i>	<i>4.696</i>	<i>4.706</i>	<i>4.716</i>	<i>4.726</i>	<i>4.736</i>	<i>4.746</i>	<i>4.756</i>	<i>4.766</i>	<i>4.776</i>	<i>4.786</i>	<i>4.796</i>	<i>4.806</i>	<i>4.816</i>	<i>4.826</i>	<i>4.836</i>	<i>4.846</i>	<i>4.856</i>	<i>4.866</i>	<i>4.876</i>	<i>4.886</i>	<i>4.896</i>	<i>4.906</i>	<i>4.916</i>	<i>4.926</i>	<i>4.936</i>	<i>4.946</i>	<i>4.956</i>	<i>4.966</i>	<i>4.976</i>	<i>4.986</i>	<i>4.996</i>	<i>5.006</i>	<i>5.016</i>	<i>5.026</i>	<i>5.036</i>	<i>5.046</i>	<i>5.056</i>	<i>5.066</i>	<i>5.076</i>	<i>5.086</i>	<i>5.096</i>	<i>5.106</i>	<i>5.116</i>	<i>5.126</i>	<i>5.136</i>	<i>5.146</i>	<i>5.156</i>	<i>5.166</i>	<i>5.176</i>	<i>5.186</i>	<i>5.196</i>	<i>5.206</i>	<i>5.216</i>	<i>5.226</i>	<i>5.236</i>	<i>5.246</i>	<i>5.256</i>	<i>5.266</i>	<i>5.276</i>	<i>5.286</i>	<i>5.296</i>	<i>5.306</i>	<i>5.316</i>	<i>5.326</i>	<i>5.336</i>	<i>5.346</i>	<i>5.356</i>	<i>5.366</i>	<i>5.376</i>	<i>5.386</i>	<i>5.396</i>	<i>5.406</i>	<i>5.416</i>	<i>5.426</i>	<i>5.436</i>	<i>5.446</i>	<i>5.456</i>	<i>5.466</i>	<i>5.476</i>	<i>5.486</i>	<i>5.496</i>	<i>5.506</i>	<i>5.516</i>	<i>5.526</i>	<i>5.536</i>	<i>5.546</i>	<i>5.556</i>	<i>5.566</i>	<i>5.576</i>	<i>5.586</i>	<i>5.596</i>	<i>5.606</i>	<i>5.616</i>	<i>5.626</i>	<i>5.636</i>	<i>5.646</i>	<i>5.656</i>	<i>5.666</i>	<i>5.676</i>	<i>5.686</i>	<i>5.696</i>	<i>5.706</i>	<i>5.716</i>	<i>5.726</i>	<i>5.736</i>	<i>5.746</i>	<i>5.756</i>	<i>5.766</i>	<i>5.776</i>	<i>5.786</i>	<i>5.796</i>	<i>5.806</i>	<i>5.816</i>	<i>5.826</i>	<i>5.836</i>	<i>5.846</i>	<i>5.856</i>	<i>5.866</i>	<i>5.876</i>	<i>5.886</i>	<i>5.896</i>	<i>5.906</i>	<i>5.916</i>	<i>5.926</i>	<i>5.936</i>	<i>5.946</i>	<i>5.956</i>	<i>5.966</i>	<i>5.976</i>	<i>5.986</i>	<i>5.996</i>	<i>6.006</i>	<i>6.016</i>	<i>6.026</i>	<i>6.036</i>	<i>6.046</i>	<i>6.056</i>	<i>6.066</i>	<i>6.076</i>	<i>6.086</i>	<i>6.096</i>	<i>6.106</i>	<i>6.116</i>	<i>6.126</i>	<i>6.136</i>	<i>6.146</i>	<i>6.156</i>	<i>6.166</i>	<i>6.176</i>	<i>6.186</i>	<i>6.196</i>	<i>6.206</i>	<i>6.216</i>	<i>6.226</i>	<i>6.236</i>	<i>6.246</i>	<i>6.256</i>	<i>6.266</i>	<i>6.276</i>	<i>6.286</i>	<i>6.296</i>	<i>6.306</i>	<i>6.316</i>	<i>6.326</i>	<i>6.336</i>	<i>6.346</i>	<i>6.356</i>	<i>6.366</i>	<i>6.376</i>	<i>6.386</i>	<i>6.396</i>	<i>6.406</i>	<i>6.416</i>	<i>6.426</i>	<i>6.436</i>	<i>6.446</i>	<i>6.456</i>	<i>6.466</i>	<i>6.476</i>	<i>6.486</i>	<i>6.496</i>	<i>6.506</i>	<i>6.516</i>	<i>6.526</i>	<i>6.536</i>	<i>6.546</i>	<i>6.556</i>	<i>6.566</i>	<i>6.576</i>	<i>6.586</i>	<i>6.596</i>	<i>6.606</i>	<i>6.616</i>	<i>6.626</i>	<i>6.636</i>	<i>6.646</i>	<i>6.656</i>	<i>6.666</i>	<i>6.676</i>	<i>6.686</i>	<i>6.696</i>	<i>6.706</i>	<i>6.716</i>	<i>6.726</i>	<i>6.736</i>	<i>6.746</i>	<i>6.756</i>	<i>6.766</i>	<i>6.776</i>	<i>6.786</i>	<i>6.796</i>	<i>6.806</i>	<i>6.816</i>	<i>6.826</i>	<i>6.836</i>	<i>6.846</i>	<i>6.856</i>	<i>6.866</i>	<i>6.876</i>	<i>6.886</i>	<i>6.896</i>	<i>6.906</i>	<i>6.916</i>	<i>6.926</i>	<i>6.936</i>	<i>6.946</i>	<i>6.956</i>	<i>6.966</i>	<i>6.976</i>	<i>6.986</i>	<i>6.996</i>	<i>7.006</i>	<i>7.016</i>	<i>7.026</i>	<i>7.036</i>	<i>7.046</i>	<i>7.056</i>	<i>7.066</i>	<i>7.076</i>	<i>7.086</i>	<i>7.096</i>	<i>7.106</i>	<i>7.116</i>	<i>7.126</i>	<i>7.136</i>	<i>7.146</i>	<i>7.156</i>	<i>7.166</i>	<i>7.176</i>	<i>7.186</i>	<i>7.196</i>	<i>7.206</i>	<i>7.216</i>	<i>7.226</i>	<i>7.236</i>	<i>7.246</i>	<i>7.256</i>	<i>7.266</i>	<i>7.276</i>	<i>7.286</i>	<i>7.296</i>	<i>7.306</i>	<i>7.316</i>	<i>7.326</i>	<i>7.336</i>	<i>7.346</i>	<i>7.356</i>	<i>7.366</i>	<i>7.376</i>	<i>7.386</i>	<i>7.396</i>	<i>7.406</i>	<i>7.416</i>	<i>7.426</i>	<i>7.436</i>	<i>7.446</i>	<i>7.456</i>	<i>7.466</i>	<i>7.476</i>	<i>7.486</i>	<i>7.496</i>	<i>7.506</i>	<i>7.516</i>	<i>7.526</i>	<i>7.536</i>	<i>7.546</i>	<i>7.556</i>	<i>7.566</i>	<i>7.576</i>	<i>7.586</i>	<i>7.596</i>	<i>7.606</i>	<i>7.616</i>	<i>7.626</i>	<i>7.636</i>	<i>7.646</i>	<i>7.656</i>	<i>7.666</i>	<i>7.676</i>	<i>7.686</i>	<i>7.696</i>	<i>7.706</i>	<i>7.716</i>	<i>7.726</i>	<i>7.736</i>	<i>7.746</i>	<i>7.756</i>	<i>7.766</i>	<i>7.776</i>	<i>7.786</i>	<i>7.796</i>	<i>7.806</i>	<i>7.816</i>	<i>7.826</i>	<i>7.836</i>	<i>7.846</i>	<i>7.856</i>	<i>7.866</i>	<i>7.876</i>	<i>7.886</i>	<i>7.896</i>	<i>7.906</i>	<i>7.916</i>	<i>7.926</i>	<i>7.936</i>	<i>7.946</i>	<i>7.956</i>	<i>7.966</i>	<i>7.976</i>	<i>7.986</i>	<i>7.996</i>	<i>8.006</i>	<i>8.016</i>	<i>8.026</i>	<i>8.036</i>	<i>8.046</i>	<i>8.056</i>	<i>8.066</i>	<i>8.076</i>	<i>8.086</i>	<i>8.096</i>	<i>8.106</i>	<i>8.116</i>	<i>8.126</i>	<i>8.136</i>	<i>8.146</i>	<i>8.156</i>	<i>8.166</i>	<i>8.176</i>	<i>8.186</i>	<i>8.196</i>	<i>8.206</i>	<i>8.216</i>	<i>8.226</i>	<i>8.236</i>	<i>8.246</i>	<i>8.256</i>	<i>8.266</i>	<i>8.276</i>	<i>8.286</i>	<i>8.296</i>	<i>8.306</i>	<i>8.316</i>	<i>8.326</i>	<i>8.336</i>	<i>8.346</i>	<i>8.356</i>	<i>8.366</i>	<i>8.376</i>	<i>8.386</i>	<i>8.396</i>	<i>8.406</i>	<i>8.416</i>	<i>8.426</i>	<i>8.436</i>	<i>8.446</i>	<i>8.456</i>	<i>8.466</i>	<i>8.476</i>	<i>8.486</i>	<i>8.496</i>	<i>8.506</i>	<i>8.516</i>	<i>8.526</i>	<i>8.536</i>	<i>8.546</i>	<i>8.556</i>	<i>8.566</i>	<i>8.576</i>	<i>8.586</i>	<i>8.596</i>	<i>8.606</i>	<i>8.616</i>	<i>8.626</i>	<i>8.636</i>	<i>8.646</i>	<i>8.656</i>	<i>8.666</i>	<i>8.676</i>	<i>8.686</i>	<i>8.696</i>	<i>8.706</i>	<i>8.716</i>	<i>8.726</i>	<i>8.736</i>	<i>8.746</i>	<i>8.756</i>	<i>8.766</i>	<i>8.776</i>	<i>8.786</i>	<i>8.796</i>	<i>8.806</i>	<i>8.816</i>	<i>8.826</i>	<i>8.836</i>	<i>8.846</i>	<i></i>
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FINISH EXTRAS

All sheet is furnished with finish 1 at no extra cost (hot-rolled, annealed, and pickled); No. 2D is available on request at no extra cost (full finish, dull, and cold-rolled); the manufacturer will furnish the price extras for finish 4 on request (standard polish on one or both sides).

PIGMENTS

Nominal prices quoted in the United States for titanium pigments from 1938-54 are shown in table 60.

Prices for titanium pigments remained unchanged during World War II; they were controlled by the Office of Price Administration from February 1942 to November 1945. After the war prices maintained a steady upward trend.

TABLE 60.—Year-end prices of titanium pigments, United States, 1938-54¹

[Cents per pound]				
Year	Anatase, Regular Grade	Anatase, Ceramic Grade	Nonchalking rutile	30 percent rutile-calcium
1938.....	15			54 1/2
1939.....	13			5 1/2
1940.....	13			5 1/2
1941.....	14 1/2		16 1/2	5 1/2
1942.....	14 1/2		16 1/2	5 1/2
1943.....	14 1/2		16 1/2	5 1/2
1944.....	14 1/2		16 1/2	5 1/2
1945.....	14 1/2		16 1/2	5 1/2
1946.....	15 1/2		17 1/2	6
1947.....	17 1/2		19 1/2	6 3/4
1948.....	18-19 1/2		20-21 1/2	7 1/2-7 3/4
1949.....	19 1/2	19 1/2	21 1/2	7-7 1/4
1950.....	21-21 1/2	21-21 1/2	23-23 1/2	8-8 1/2
1951.....	21-21 1/2	21-21 1/2	23-23 1/2	8-8 1/2
1952.....	21-21 1/2	21-21 1/2	23-23 1/2	8-8 1/2
1953.....	22 1/2	22 1/2	24 1/2	8 3/4
1954.....	22 1/2	22 1/2	24 1/2	8 3/4
1955.....				
1956.....				
1957.....				

¹ Price quoted for bags, carlots, minimum 20 tons. Data not available before 1938.

TABLE 61.—Year-end prices of ferrotitanium, United States, 1938-54¹

(Low-carbon—dollars per pound of contained titanium; high-carbon and medium-carbon—dollars per short ton of alloy)

Year	Low-carbon			High-carbon		Medium-carbon					
	Maximum carbon, percent	Titanium, percent	Dollars/lb. of titanium	6-8 percent carbon		3-5 percent carbon		3-4.5 percent carbon		2-4.5 percent carbon	
				Titanium, percent	Price per short ton	Titanium, percent	Price per short ton	Titanium, percent	Price per short ton	Titanium, percent	Price per short ton
1938.....		40-45	\$1. 23	15-18	\$142. 50	15-18	\$157. 50				
	0. 10	20-25	1. 35								
1939.....		40-45	1. 23	15-18	142. 50	15-18	157. 50				
	. 10	20-25	1. 35								
1940.....		40-45	1. 23	15-18	142. 50	15-18	157. 50				
	. 10	20-25	1. 35								
1941-47.....		40-45	1. 23	15-20	142. 50	15-20	157. 50				
	. 10	20-25	1. 35								
1948.....	. 10	20-25	1. 40	15-20	142. 50	15-20	157. 50	17-21	\$175		
	. 10	38-43	1. 28	15-18	160. 00						
	. 10	40-45	1. 23								
1949.....	. 10	20-25	1. 40	15-18	160. 00			17-21	175		
	. 10	38-43	1. 28								
1950.....	. 10	20-25	1. 40	15-18	167. 00			17-21	183		
	. 10	38-43	1. 28								
1951.....	. 10	20-25	1. 50	15-18	177. 00			17-21	195		
	. 10	38-43	1. 35								
1952.....	. 10	20-25	1. 50	15-18	177. 00					17-21	\$195
	. 10	38-43	1. 35								
1953.....	. 10	20-25	1. 50	15-18	187. 00					17-21	210
	. 10	38-43	1. 35								
1954.....	. 10	20-25	1. 50	15-18	187. 00					17-21	210
	. 10	38-43	1. 35								

¹ Price quoted for ton lots.

FERROTITANIUM

All producers of titanium master alloys for sale to the iron and steel industry sell at competitive prices. The manufacturers of master alloys will occasionally absorb losses temporarily rather than risk disturbing the market by adjusting prices. Similarly they may take a temporary loss on some items to meet competition or develop new markets.

Nominal prices for low-carbon, high-carbon, and medium-carbon ferrotitanium in the United States from 1938 through 1954 are shown in table 61. On January 1, 1955, the price of high-carbon ferrotitanium was raised to \$192 per ton and of medium-carbon ferrotitanium to \$215 per ton.

TITANIUM TETRACHLORIDE

Inasmuch as over 4 pounds of titanium tetrachloride is needed to produce each pound of sponge titanium, the price of the tetrachloride directly affects the price of the metal. Prices at the end of the year remained constant from 1951-53, but by the end of 1954 a substantial reduction had taken place. Price quotations per pound at the end of the year for 1951-54 follow:

	1951-53	1954
Tank cars, works.....	\$0. 44½	\$0. 39¾
Drums, carlots, works.....	. 45½	. 40¾
Less than carlots, works.....	. 48½- 56½	. 43¾

These prices are deceiving, as most of the sponge producers manufacture titanium tetrachloride for their own use at costs considerably less than the market price of the compound. Any large consumer of titanium tetrachloride

could probably buy it much cheaper than the quoted market price if he bought in quantity.

PRODUCTS FOR CERAMIC USE

Materials sold as mediums for adding titanium dioxide to ceramic products include ceramic rutile, frit rutile, milled ilmenite, and Ceramic-Grade pigment. In April 1955 the following prices were quoted for these products: Ceramic rutile, 16½ cents per pound; frit rutile, 4½ cents per pound; milled ilmenite, 2 cents per pound; and Ceramic-Grade pigment, 22½ cents per pound. These prices are for carlots f. o. b. producing plant. In the case of frit rutile and milled ilmenite, these prices are lower than those of a year ago, when the prices were quoted as 7½ and 2½ cents, respectively.

PRODUCTS FOR ELECTRICAL USE

Materials sold as additives in compounding ceramic bodies with special electrical properties include barium titanate, barium-strontium titanate, calcium titanate, lead titanate, magnesium titanate, and strontium titanate. In April 1955 the Titanium Alloy Manufacturing Division of National Lead quoted the following prices per pound for these products: Barium titanate, 37 cents; barium-strontium titanate, 60 cents; calcium titanate, 38 cents; magnesium titanate, 52 cents; and strontium titanate, 83 cents. All prices are for carlots, f. o. b. Suspension Bridge, N. Y. In all instances, these prices are substantially lower than those given in January 1954. For example: Strontium titanate had come down from 91 cents to 83, and magnesium titanate had been reduced from 54 cents to 52.

CHAPTER 11. RESEARCH AND DEVELOPMENT

Because titanium metal has only been produced commercially since 1948, numerous research and development projects have been underway in an attempt to solve the many problems in producing and using the metal. Most of the effort has been put forth by the United States Department of Defense, as it was anticipated that titanium could be used in many military applications where its unique properties outbalanced the extra cost of using it. The majority of the experiments have been carried out by private companies and institutions so that they could gain experience in the use of the metal. The Federal Bureau of Mines, employing its own funds and funds supplied by other Government agencies, was instrumental in interesting private industry in the metal and in helping to solve many of the production and fabricating problems involved in its use.

GOVERNMENT PROGRAMS

UNITED STATES DEPARTMENT OF DEFENSE

Beginning in 1946 the United States Department of Defense, through the Departments of the Army, Navy, and Air Force, continuously sponsored a titanium research and development program. By early 1955, 4 Government and 24 industrial or institutional groups had worked on individual projects costing \$100,000 or more each. The total cost of work assigned to these 28 laboratories amounted to \$8,344,000. Several hundred other projects have been sponsored; the cost involved has been as low as \$500 for some projects.

To develop detailed plans and coordinate the work of the United States Department of Defense agencies responsible for carrying out the titanium program, a Steering Group on Titanium Research and Development was formed in August 1954 under the sponsorship of the Assistant Secretary of Defense for Research and Development. The function of the Steering Group was to formulate United States Department of Defense policy on titanium and to direct Army, Navy, and Air Force efforts along lines that will achieve maximum results. The Assistant Secretaries of Defense for Applications Engineering and Supply and Logistics have both designated members of the

group. In addition, there are a member and a deputy member in the group to represent the Army, the Navy, and the Air Force.

To insure that everything possible was done to remove the obstacles to the use of titanium wherever performance advantage justifies the additional cost, the Steering Group outlined a six-point program of support, which included:

1. An expanded research program to fill in missing links in the data secured from past work and to establish a basis for improved alloys.
2. Assistance to the titanium industry on developing improved melting and fabricating methods and equipment.
3. Making contracts with producers of engines, airframes, and certain other types of military equipment for experimental fabrication and testing of titanium components.
4. Placing direct Government orders with the titanium industry for mill products for experimental fabrication into military components.
5. Encouraging useful applications of titanium in military aircraft where such applications would be economically feasible at the price level titanium should reach under large-scale production.
6. Provisions for the use of titanium in selected military applications, other than aircraft, where titanium would be particularly advantageous and where such use would be economically feasible at the price level titanium should eventually reach.

To assist the United States Department of Defense in carrying out this program a Titanium Metallurgical Laboratory was established at Battelle Memorial Institute in November 1954. The purpose of the laboratory was: To collect and disseminate information on the status of titanium research and development; to provide technical advisory services to producers, melters, and fabricators of titanium metal; to provide assistance and advice to the Steering Group in its appraisal of United States Department of Defense research and development program; to assist Government agencies and their contractors in developing data for preparing specifications for titanium metal and mill products; and to conduct laboratory investigations to ascertain the causes of problems that the fabricators may encounter.

DEPARTMENT OF THE ARMY

Titanium research has been concentrated in the Ordnance Corps because of the possibility that this metal will be used in various weapons where its high strength-to-weight ratio would be important. Early in 1946 Army Ordnance

began investigating the characteristics of samples of cast titanium supplied by Metal Hydrides, Inc. In the period 1946-49 the Ordnance Corps supported projects dealing with titanium alloy systems, heat treatment for titanium alloys, mechanical properties at high and low temperatures, ballistic properties, and welding characteristics. This research was carried on at the Watertown (Mass.) Arsenal and at the College Park (Md.) Station of the Federal Bureau of Mines.

During 1950 the program had advanced to the stage that a great number of items using titanium alloys were considered for construction. The industry was getting started in this year. No standard alloys were available, and many problems of fabrication were unsolved, so most of the projects were directed along lines of basic research.

In 1951 the situation appeared to be critical in that not enough sponge was available to meet all the anticipated needs of the military establishment. To help remedy this situation, the Ordnance Corps supplied funds to the Bureau of Mines to enable it to do research on the development of a continuous process for producing sponge. As part of this program, a larger pilot plant was constructed at Boulder City, Nev., during the 1952 fiscal year. It soon became evident that development of a continuous reactor would be difficult; work was then concentrated upon improving the Kroll process.

The cost of titanium was of great concern to the Army, and programs that showed promise of reducing it were undertaken. One method of reducing cost was to stimulate the industry to produce more mill products. The Department of the Army let out contracts with 3 semi-fabricators for mill products amounting to 125,000 pounds of wrought material to be used by the Army.

From 1952-55 a strong titanium-research program was continued in many areas, such as development of high-strength alloys, fundamental physical metallurgy, casting, welding, machining, and actual fabrication of prototypes of ordnance materiel. This program has decreased each year and probably will not expand again until the price of titanium is low enough so that the Army can afford it. However, if a national emergency were to occur, the research on and uses of titanium would be expanded in spite of the cost.

The actual projects have been carried out at a wide variety of facilities, including the Army's own Watertown (Mass.) Arsenal, Frankford (Pa.) Arsenal, Picatinny (N. J.) Arsenal, and Redstone (Ala.) Arsenal. In 1953 and 1954 over 20 companies and institutions were engaged in projects sponsored by the Army.

DEPARTMENT OF THE NAVY

The Department of the Navy has a diversified interest in titanium. The Bureau of Ships, Bureau of Aeronautics, Bureau of Ordnance, and the Office of Naval Research have all been sponsoring or carrying out titanium research and development projects.

The Bureau of Aeronautics first became interested in titanium as a structural material in 1946. Between 1946 and 1949 this Bureau conducted studies at the Naval Air Experimental Station in Philadelphia on the metallurgy, fabrication, and design of titanium products. Corrosion studies were made at exposure sites near Norfolk, Va., and alloy-development work was sponsored at facilities of the Federal Bureau of Mines and P. R. Mallory & Co.

By 1951 the three bureaus and the Office of Naval Research had titanium programs underway. The main effort was concentrated in the Bureau of Aeronautics, which was attempting to solve some of the fabrication problems presented by titanium.

In 1955 the situation remained somewhat the same, with the bulk of practical titanium research and development still lodged in the Bureau of Aeronautics. An active program was underway on the development of titanium alloys, fabrication studies, heat treatment, welding, investigation of corrosion resistance, experimental applications, and determination of design and shop properties of titanium and its alloys.

The bulk of the basic program on research in titanium has been conducted by the Office of Naval Research. The physical metallurgy of titanium has been studied, and a somewhat larger program has been concerned with the extractive metallurgy of titanium. The objective was to provide a comprehensive collection of reliable data on titanium and its compounds and on other compounds that might be useful in developing of improved processes for producing titanium.

A major part of the titanium program at the Bureau of Ships has been related to the use of titanium in ship and machinery design. Consideration has been given to the fatigue properties of the metal, corrosion characteristics in marine environments, and properties associated with steam equipment. The United States Naval Experiment Station has carried on much of the program, which included simulated service tests of prototype machinery components made of titanium.

At the Bureau of Ordnance an intensive program on titanium armor has been underway, with the objective of assessing various metallurgical and processing variables to determine if ballistic performance could be

obtained superior to that of the materials now used for armor. The performance characteristics of all materials suitable for protective armor were tested on an equal weight basis with titanium.

Each of the bureaus plans to continue development and testing to include fabrication studies, welding, investigation of corrosion resistance, and specific applications ranging from fasteners to be used in aircraft to large projects involving the use of sheet titanium as a construction material.

DEPARTMENT OF THE AIR FORCE

Research and development in titanium were begun in earnest by the Air Force in 1947. Programs were initiated in alloy development, investigation of refractories, and reduction processes. This included the titanium-alloy development program at Battelle Memorial Institute.

By 1950 investigations of the mechanical and welding properties of commercially pure, carbon-free titanium were completed. As a basis for the alloy-development program, work was done on phase diagrams; most of the thermal-expansion work was conducted at Wright Air Development Center, Dayton, Ohio. By 1951 the tentative phase diagrams for 10 alloying elements were completed. Studies had also been made of the creep and fatigue properties of titanium, radiographic inspection methods, weldability, and analysis methods for most of the elements considered likely to occur in titanium.

The development, in 1952, of the 3Mn complex alloy proved the feasibility of heat-treatable titanium alloys that could be formed in the solution heat-treated condition, then aged to high tensile strengths.

In 1953 a relatively high temperature, weldable alloy was developed (Ti-6Al-4V). This alloy is a sheet, plate, bar, and forging material that can be used in elevated temperature applications, for example, disks, spacers, and compressor blades for turbojet engines.

To utilize the corrosion resistance of titanium, work was done on developing a protective system utilizing titanium as a coating material for other metals. An electrodeposition process was worked out and a patent applied for in 1954 for this process, called "Titanizing."

In 1954 researchers became fully aware of the embrittling effect of hydrogen on titanium. An intense internal research program at Wright Air Development Center provided a solution by establishing limits for the hydrogen contents of various alloys. To implement these limits into production, the Air Force initiated an analysis program to evaluate and standardize analytical techniques and methods and to determine the

uniformity obtained in production and thereby establish satisfactory quality-control procedures.

The USAF research and development program in titanium encompasses physical metallurgy, alloy development, and a study of the metallurgical variables of titanium. Its objective up to 1955 was a series of alloys tailored to general or special purpose applications. A new high-temperature alloy, Ti-7Al-3Mo, which has much better hot strength than 6Al-4V alloy, was developed in 1955 as a result of this program.

The research and development efforts of the Air Force on titanium are carried out in both internal and external facilities. External projects sponsored by Wright Air Development Center in 1955 comprised 50 contracts with 8 universities, 5 research institutes, and 4 industrial organizations. Contractual work for WADC from 1951-55 amounted to \$3,850,000. It was estimated that the internal projects in this same period cost approximately \$1,200,000.

FEDERAL BUREAU OF MINES

In 1938 the Bureau of Mines, Tucson, Ariz., laboratory began investigating the technology of titanium, a heretofore neglected although plentiful element in the earth's crust. A critical survey and small-scale trial of virtually all suggested methods for producing titanium metal were made by Bureau personnel, and the magnesium reduction of titanium tetrachloride was selected as the one most suitable for quick development for tonnage production and evaluation of semifabricated titanium products.

In 1942 development of the Kroll process was begun at the Salt Lake City laboratory. Using an improved modification of the Kroll process, titanium production was increased from a few grams to 15 pounds per batch. Further development work on the Kroll process was transferred in 1944 to the Boulder City, Nev., laboratory, where considerable work was done on the production of ductile-grade titanium in 100-pound batches. Research on the physical metallurgy of converting titanium powder into wrought metal and alloys was conducted at Salt Lake City.

By 1946 samples of the metal were being distributed free to investigators who wished to experiment with the metal and report their findings. Free distribution of this material probably did more to accelerate the interest of industry than any other stimulus. Production of titanium at Boulder City was subsequently increased to 200-pound batches.

As pilot-plant production of ductile titanium requires pure titanium tetrachloride, a procedure was developed to purify the commercial grade of crude titanium tetrachloride available from manufacturers. Purification of the titanium

sponge was initially effected by leaching to remove magnesium chloride. The purified sponge was then ground to produce titanium powder. The titanium powder could not be melted easily and required powder-consolidation techniques. As this purification operation introduced other objectionable impurities, such as oxygen, nitrogen, and hydrogen, a vacuum-distillation process was developed to produce a high-quality titanium sponge that could be melted.

A special new \$500,000 pilot plant of 1-ton-per-day capacity was completed in 1952 and was used to test improved equipment developed in laboratory studies and to produce high-purity metal for use in special Army Ordnance military applications. The Bureau of Mines was requested to produce titanium sponge metal in 1953 for national defense, to supplement the inadequate production by industry, and from July 1953–September 1954, the Bureau's Boulder City, Nev., titanium pilot plant produced 246 short tons of titanium for the General Services Administration under Contract DMP-76. The agreement, signed April 30, 1953, and terminated in October 1954, permitted minor capital improvements and equipment alterations designed to decrease production cost. Likewise, this program enabled the Bureau to obtain a more accurate cost evaluation of titanium-production processes and facilitated certain phases of the research program that required continuous plant operations.

In May 1955 the Wah Chang Corp. signed a cooperative agreement with the Bureau of Mines to conduct research and development on an improved process for producing titanium sponge metal. As a result of this agreement the pilot plant at Boulder City, Nev., was reactivated for the duration of the project.

By 1955 experiments on electrorefining at the Boulder City, Nev., Station resulted in development of an electrolytic cell for producing high-purity metal having a hardness less than 80 BHN from offgrade sponge and scrap metal. Work being done in 1955 consisted of refining titanium from binary alloys to ascertain from which elements, used as alloying constituents, titanium could be electrorefined.

Studies by the Bureau of Mines at College Park, Md., have developed methods of consolidating titanium powder into solid, nonporous metal, heat treatment, welding, stretch forming, and other methods of fabrication and have provided fundamental information on corrosion properties of ductile metal and some alloy systems. Other contributions have been the development of sampling and analytical techniques and the production of prototypes of special military equipment. Outstanding de-

velopments in this line have been the mortar base plate and the submarine exhaust muffler.

The Bureau conducted drilling investigations to develop domestic sources of titanium minerals to meet increasing industrial demands during World War II. A result of this work was disclosure of an important heavy-sand concentration at Trail Ridge, Fla. Subsequently this area was mined by Du Pont for titanium minerals and in 1954 was a large producer of ilmenite.

Relatively large scale tests were conducted successfully in 1947 at the Bureau of Mines Boulder City, Nev., laboratory, in cooperation with the National Lead Co., on the removal of iron from ilmenite by electric smelting. Approximately 15 tons of slag containing 65 to 67 percent TiO_2 was produced from ore, containing 30 to 45 percent TiO_2 , coke, and small quantities of calcium and magnesium fluxes, producing a material suitable for titanium dioxide pigment. The iron content of the ore, which, in the usual chemical treatment, is converted to cheap ferrous sulfate, was obtained as a pig iron of better potential market and strategic value than the sulfate. Earlier thermodynamic studies at the Bureau of Mines Berkeley, Calif., laboratory on selective reduction of iron in ilmenite by hydrogen, carbon monoxide, and carbon had indicated that carbon was the only effective reducing agent.

Work was begun in early 1954 at the Bureau of Mines Albany, Oreg., Electrodevelopment Laboratory to develop a smelting process for utilizing ilmenite produced as a byproduct of monazite-dredging operations in Idaho. The tests indicated that a high-titanium slag (80–84 percent TiO_2) and a good grade of pig iron could be produced from the Idaho ilmenite.

In 1953 the Albany, Oreg., laboratory began work for Army Ordnance on the problems connected with casting titanium. A number of consumable-electrode casting furnaces were built, and techniques were developed for casting titanium with a minimum of contamination. Titanium scrap was successfully used in some of the casting experiments.

The Bureau of Mines, Rolla, Mo., Station has conducted extensive investigations on processing and utilization of the titanium minerals in Hot Spring County, Ark. This work, described in Bureau reports of investigations, included studies of drilling, mineral dressing, smelting, chlorination, and use of this ore for welding-rod coatings.

Other laboratory investigations at Rolla, Mo., developed mechanical and thermal methods for conservation and recovery of a low-grade ilmenite concentrate and an iron oxide concentrate from "black sands," a waste product of

the Reynolds Metals Co. modified Bayer alumina plant at Bauxite, Ark. Utilization of this low-grade ilmenite concentrate would depend on development of smelting techniques for producing high-titania slags from this material.

Laboratory investigations, supplemented by pilot-plant tests by the Bureau at College Park, Md., in 1950 developed a process for treating titaniferous ores from Tahawus, N. Y., and Woonsocket, R. I., by sintering with carbon and soda ash, grinding, separating the metallic iron magnetically, and treating the nonmagnetic fractions for the recovery of titania, soda, and byproducts. Before this work, an investigation was conducted at the Bureau's Minneapolis Station on smelting of vanadium-bearing titaniferous sinter in an experimental blast furnace for recovering vanadium, and small-scale tests were made at Berkeley, Calif., on the selective reduction of iron in titaniferous iron ores.

GENERAL SERVICES ADMINISTRATION

The General Services Administration has the authority to assist pilot-plant tests on any new processes that, in the opinion of a technical committee acting on a confidential basis, appear technically feasible but are not being developed as vigorously as desired.

Three research contracts were in effect as of June 1955, with a total maximum cost to the Government of \$1,844,285. These contracts may be summarized as follows:

Horizons Titanium Corp. Effective date, July 1, 1954. Termination date, July 1, 1955. Maximum cost to the Government, \$564,300. The contract was granted for Horizons Titanium Corp. to do research and piloting of an electrolytic process for the production of titanium metal.

Horizons, Inc. Effective date, April 29, 1955. Termination date, January 29, 1956. Maximum cost to the Government, \$96,490. The contract was granted to enable Horizons, Inc., to do research and piloting of a process to produce titanium sponge or its equivalent from titanium scrap.

National Research Corp. and Monsanto Chemical Co. Effective date, May 19, 1955. Termination date, January 19, 1957. Maximum cost to the Government, \$1,183,495. The contract was to enable these two companies to jointly work on research and piloting of a fused-salt process for the production of titanium metal from $TiCl_4$ and commercially available sodium.

In all of the contracts the contracting company was to work without fee, but the Government would pay the cost of the operation. If a process was developed that was put into commercial production within 10 years, the Government was to be reimbursed for its investment and would receive nonexclusive royalty-free licenses on inventions and patents that were developed.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

The Langley Laboratory of the National Advisory Committee for Aeronautics has carried out experiments to determine certain mechanical properties of a titanium alloy and to make a structural efficiency study of that alloy.

NATIONAL BUREAU OF STANDARDS

The functions of the National Bureau of Standards, United States Department of Commerce, include the determination of physical constants and properties of materials; advisory services to Government agencies on scientific and technical problems; and inventions and development of devices to serve special needs of the Government. Projects connected with titanium have been conducted on a limited scale but include a continuing project on the electrodeposition of titanium that was initiated in 1952 and a completed project on the preparation of pure titanium tetrachloride. These two projects were sponsored, respectively, by United States Army Ordnance and the Office of Naval Research.

NATIONAL ACADEMY OF SCIENCES

In 1951 the National Research Council of the National Academy of Sciences, conducted a study of the titanium situation for the United States Department of Defense. The council completed a report on a proposed program on basic research in extractive metallurgy of titanium that served as a guide for the United States Defense Department in some of its titanium research and development programming.

The Materials Advisory Board of the National Academy of Sciences reviewed all applications by industry for Government assistance in developing new processes and plants. The committee also makes periodic inspections of some of the facilities that have been granted assistance and thus checks the progress of the work undertaken under Government contract.

INDUSTRY-SPONSORED PROJECTS

In 1953 and 1954 at least 100 companies and laboratories were engaged in various phases of titanium research and development. A large percentage of the research in private institutions was under Government sponsorship. Non-Government research was undertaken by companies that were already in some phase of the titanium industry or were interested in becoming a part of it. This research was carried

out in the companies' own shops or laboratories or in university and consulting-firm laboratories. As of May 1955, over 400 individual projects were underway, of which 267 were sponsored by the Government.

In 1955 the United States Air Force issued five publications entitled "Titanium and Titanium Alloys Program," Books 1-5, listing research and development projects underway in the United States in 1954 and early 1955. The list of companies working on titanium projects was limited to those that responded to a questionnaire; however, the publications do give a good picture of the scope and extent of the research and development projects underway at the time of the survey. Table 62, in the appendix to this chapter, summarizes these reports, listing also the projects carried out in Government facilities. In these reports titanium research was broken down into 13 categories, as follows: Reduction and chemical thermodynamics, melting, chemical analysis, powder metallurgy, alloying and its effects, heat treatment, mechanical properties, surface properties and protection, brazing and welding, hot and cold shaping, machining and grinding, casting, and applications. The interest of private industry in each of these fields of investigation (exclusive of Government-sponsored projects) will be more fully discussed.

REDUCTION AND CHEMICAL THERMODYNAMICS

This phase of research has received much attention because development of a new process for producing titanium sponge would result in revamping of the metal-producing industry. Interest has centered on the production of metal by electrolytic reduction; however, all the plants in operation in 1954 produced titanium sponge by reduction of titanium tetrachloride with magnesium. Historically, before a company can become a commercial producer it must spend a year or two producing sponge on a pilot-plant scale. The Crane Co. operated a pilot plant at Chicago, Ill., for 3 years before it went into commercial production. The other producers—Titanium Metals Corp. of America, E. I. du Pont de Nemours & Co., Inc., and Dow Chemical Co.—operated pilot plants for long periods. The Glidden Co. in 1954 was reportedly constructing a pilot plant at Hawkins Point, Md., to make titanium metal by an electrolytic process. Electro Metallurgical Co., Niagara Falls, N. Y., has carried out a research and development program for 5 years at a cost of \$2 million to produce titanium by a sodium-reduction process. Battelle Memorial Institute has operated a pilot plant for Kennecott Copper Co. since 1952. Kennecott began research on

the production of titanium metal in 1948. United International Research has a pilot-plant operation for producing titanium metal by electrolytic means. The Western Pyromet Co. set up a pilot plant at Manteca, Calif., in a Government-owned magnesium plant in 1954. Horizons, Inc., has conducted experimental work for many years and received a Government loan in 1954 to erect a pilot plant to produce titanium sponge by a new electrolytic process. In 1954 Monsanto Chemical Co. and National Research Corp. were doing research on producing crystalline titanium. National Distillers Products Corp. was conducting pilot-plant research on a process for sodium reduction of titanous chloride. Armour Research Foundation was working on a new reduction process for a member of industry in 1954. In early 1955 the Wah Chang Corp. entered into a cooperative agreement with the Bureau of Mines to investigate improvements of the Kroll process.

Other research that has been and continues to be conducted in this category is: Study of the thermodynamic properties of titanates; investigation of the crystal growth of titanium in molten-salt electrolysis; phase-equilibria studies of systems containing titanium, titanium halides, and magnesium; determining the physical and thermodynamic properties of titanium and its compounds; developing and improving sponge-producing processes; studying methods of removing oxygen from titanium by selected reducing agents; and evaluating processes for producing molten titanium metal by hydrogen reduction of titanium tetrachloride.

MELTING

Most of the melting research has been carried out by the four companies engaged in melting titanium on a commercial scale: Mallory-Sharon Titanium Corp., Republic Steel Corp., Rem-Cru Titanium, Inc., and Titanium Metals Corp. of America. Chase Brass & Copper Co., a subsidiary of Kennecott Copper Co., built a melting furnace in 1954 to obtain experience in melting and casting titanium. Westinghouse Electric Co. has conducted melting experiments with various metals, including titanium, and is interested in purifying the metal by zone melting. Battelle Memorial Institute has carried on melting research for Republic Steel Co. Harvey Machine Co. has run melting experiments for over a year and by mid-1955 was melting sponge on a semicommercial scale.

The metal currently produced is double-arc-melted, using consumable electrodes, but research is being done on levitation melting, induction melting, and zone melting. The interested companies are also trying to develop methods for melting massive scrap and sponge.

CHEMICAL ANALYSIS

A large number of firms are engaged in trying to develop better methods for chemically analyzing titanium, as almost any firm that uses titanium must have some method of checking the metal for impurities. Present costs for analysis are quite high, so most of the companies want to develop cheaper and faster means of carrying out this work. Methods of chemical analyses being studied are: Wet chemical analysis, spectroscopic analysis, polarography, flame photometry, and X-ray fluorescence.

Some of the firms conducting experiments in this field, aside from the sponge producers, are: A. O. Smith Corp., Chase Brass & Copper Co., General Electric Co., Massachusetts Institute of Technology, Metal Hydrides, Inc., New Jersey Zinc, and Republic Steel Corp. A more complete listing may be found in table 62 in the appendix to this chapter.

POWDER METALLURGY

Relatively few firms are reported to be investigating the powder metallurgy of titanium. Brush Development Laboratories Co. has been engaged in titanium research since 1948. Kennametal, Inc., has developed a powdered titanium carbide for use in high-temperature and high-speed operations. Metal Hydrides, Inc., is interested in developing alloy powders and alloys of titanium with copper, chromium, nickel, and other metals. United International Research Co. was doing research on powdered metal and alloys in 1954.

Interest has centered on producing titanium-alloy powder from various materials, including scrap; producing rods, wire, and ingots from titanium powder; and developing fabrication techniques for improving the properties of materials produced from titanium powder.

ALLOYING AND ITS EFFECTS

Since the properties of titanium vary greatly with the impurities present and the alloying elements added, much time has been devoted to studying the effects of various elements on the properties of titanium. Much of the work has been done on developing ternary phase diagrams. The effects of carbon, nitrogen, oxygen, and hydrogen upon the properties of titanium have been especially studied. Researchers have worked on the development of titanium alloys having superior strength and toughness, alloys to be used at high temperatures, ductile alloys with physical and mechanical properties suitable for aeronautical applications, and alloys that could be welded.

In 1954 Rem-Cru Titanium Corp. developed and put into production a titanium-based alloy

containing 5 percent aluminum and 2.5 percent tin that could be readily welded. Mallory-Sharon Titanium Corp. and Titanium Metals Corp. of America brought out a 6-percent-aluminum, 4-percent-vanadium alloy that had been developed by Armour Research Foundation. Battelle Memorial Institute was responsible for developing an alloy containing 3 percent manganese and 1 percent each of iron, chromium, vanadium, and molybdenum, and this alloy was put into production in 1954 by Mallory-Sharon Titanium Corp. Other companies doing alloy research include Firth Stirling Corp., which has developed a new titanium carbide cutting material, and the General Electric Co., which has worked on alloys for high-temperature applications.

Although interest in alloying and its effects is widespread, most of the research projects in this field are sponsored by the Government.

HEAT TREATMENT

A great number of studies have been made on various aspects of heat treatment, but these have largely been conducted under Government sponsorship. The four semifabricators, however, continue to investigate the heat treatment of their products. The General Electric Co. in 1954 investigated the proper heat treatment for certain titanium compressor disks.

Studies in the field of heat treatment have included: Investigation of the kinetics of phase transformation and resultant microstructure; determination of the effect of reheating titanium after quenching; development of the principles governing the relationship of microstructure and mechanical properties of titanium alloys; examination of the structures induced in titanium metal by thermal and mechanical treatments; evaluation of the heat-treatment response of several titanium alloys; and the determination of the maximum crystal size that can be expected in titanium alloys under critical conditions of processing.

MECHANICAL PROPERTIES

Most of the fabricators do research on the mechanical properties of titanium under their own initiative. Many such projects are also conducted by private industry under Government sponsorship. These projects are set up to investigate a wide variety of mechanical properties: Hardness, impact strength, notched fatigue, tensile strength, stress rate, strain rate, temperature fatigue, and creep resistance. Other projects are set up to determine how these mechanical properties are affected by such factors as surface finish, interstitials, alloying, internal stress, microstructure, and rate of loading.

SURFACE PROPERTIES AND PROTECTION

Various experiments are being performed to develop protective coatings for titanium. These include studies in nitriding the surface, siliconizing the surface, surface hardening with metalloid elements, electroplating titanium, carbonitriding titanium, depositing vapor coatings on titanium, and coating titanium by chemical conversion. Some of these investigations are aimed at merely devising means of hardening the surface, while others are aimed at protecting the metal against the absorption of various gases.

Studies of the surface properties include: Establishing the principles that govern seizing and galling, determining wear characteristics, and investigating corrosion properties and the kinetics of oxidation.

Companies and institutions doing research on surface properties in 1954 include: Kennecott Copper Co., which was running experiments on seizing and galling; General Motors Corp., which was working on protection of titanium during forging; Georgia Institute of Technology, which was investigating surface oxide films on titanium; and Mallory-Sharon Titanium Corp., which was studying the effect of furnace atmospheres on surface properties.

BRAZING AND WELDING

In 1954 several companies were investigating brazing and welding independent of Government support. These included Kennecott Copper Co., Solar Aircraft Co., and Union Carbide & Carbon Co.

These companies were interested in improving welding and brazing techniques. Studies have been made of the surface embrittlement caused by exposure to weld heat and various methods of protecting the heated surface from atmospheric contamination have been developed. Spot- and seam-weld characteristics of titanium were being determined, and methods of welding titanium to its alloys and other metals were being developed.

HOT AND COLD SHAPING

Most of the companies doing independent research on hot and cold shaping are in the business of producing fabricated or semi-fabricated parts from titanium. Harvey Machine Co. has done much development work on the extrusion of titanium. Chase Brass & Copper Co. has also worked on the extrusion and fabrication of titanium into commercial shapes. Mallory-Sharon has conducted experiments on rolling titanium. Superior Tube Co. is developing new methods for shaping sheet

for welded tubes. Ryan Aeronautical Co. began titanium research in 1951 and was the first company to form titanium by the drop-hammer process. Chance Vought Aircraft has done work on cold-forming titanium sheets. Boeing Aircraft Co. has investigated the fabricating characteristics of titanium.

From this it may be seen that research in this field centers on hot- and cold-rolling methods, extrusion and drawing techniques, and drop-hammer-forging improvements.

MACHINING AND GRINDING

The Norton Co., North American Aviation, Inc., and Curtiss-Wright Corp. have done much research on machining and grinding, chiefly under Government sponsorship. Kennecott Copper Co. has sponsored work on this problem in its own laboratories, at Battelle Memorial Institute, and at New York University. The Glenn L. Martin Co. has done work on drilling and machining. North American Aviation has experimented with a chemical milling process. Rem-Cru Titanium, Inc., has a continuing program to develop new machining practices, as do Mallory-Sharon Titanium Corp. and Titanium Metals Corp. of America.

Research has centered on determining the optimum machining practices for shaping, milling, drilling, broaching, reaming, tapping, lathe turning, and sawing. Investigators are evaluating cutting fluids, lubricants, and tool life. They have also developed and improved methods for commercially grinding titanium.

CASTING

Wisconsin Centrifugal Foundry, Inc., in cooperation with Armour Research Foundation, has worked on a method for centrifugal casting of titanium. National Research Corp., with Monsanto Chemical Co., has developed a method of shaping castings; it licensed its process to the Titanium Casting Corp. (a division of Howard Foundry Co.). A few other companies, mainly under Government contract, have been developing and improving new casting methods for titanium.

APPLICATIONS

Because of the high cost of titanium, not many private companies are doing research on substituting titanium for commercial applications. Most of the research along this line is sponsored by the military establishment and is concerned with applications where weight saving or corrosion resistance is the primary consideration and cost secondary. Kennametal, Inc., has experimented with using titanium car-

bide parts in a gas turbine. Pressed Steel Co. developed titanium bolts to be used mainly in aircraft. The Crane Co. has been experimenting with various valves made of titanium. AiResearch Manufacturing Co. has been investigating the substitution of titanium for aluminum in centrifugal compressor wheels. Bendix Aviation Corp. has used titanium experimentally in valves and cylinders. Chance Vought Aircraft Corp. successfully developed titanium engine shrouds. Northrop Aircraft, Inc., has been evaluating titanium fasteners. E. I. du Pont de Nemours & Co., Inc., is concentrating on finding civilian applications for titanium. This company builds parts and equipment to be used by the food-processing and chemical in-

dustries, then tests the parts in actual operations.

Many applications being developed by various military groups could be used by private industry if the price of titanium were to drop considerably. Some applications that have been worked on are: Use of titanium metal in hydraulic piping, titanium in high-speed ship-propeller shafting, titanium rudders for small craft, titanium in radar antennas and masts, titanium-alloy propeller blades, jet-engine components, armorplate, helicopter rotor blades, wing sections for airplanes, airplane-engine shrouds and firewalls, airborne gears, aft fuselage sections of airplanes, jet pods, landing gear, and salt-water piping systems.

APPENDIX TO CHAPTER 11

TABLE 62.—Summary of titanium metal and alloys research and development projects in the United States in 1954

Code No.	Research facility ¹	Category being investigated ¹												
		Reduction and chemical thermodynamics	Melting	Chemical analysis	Powder metallurgy	Alloying and its effects	Heat treatment	Mechanical properties	Surface properties and protection	Brazing and welding	Hot and cold shaping	Machining and grinding	Castings	Applications
1a	Aircraft Engineering Corp.													9u
2a	AiResearch Manufacturing Co.													3u, 2a
3a	Alfred University		7u										7u	
4a	Allegheny-Ludlum Steel Corp.			4a										5u
5a	American Locomotive													7u
6a	American Machine & Foundry Co.													
7a	Armour Research Foundation		7u, 16u, 3u	7a, 7u		3u, 7u	3u, 7u	3u, 7u	7u	7s, 3u	1t		16u	
1b	Battelle Memorial Institute	20u	7u	3u, 1b		3u, 7u	3u, 7u	3u, 7u		3u, 7u	3u		6u	2b
2b	Bell Aircraft Co.													3b
3b	Bendix Aircraft Corp.													4b, 2u, 9u, 3u
4b	Boeing Aircraft Co.							4b, 2u			2u, 3u			
5b	Borg-Warner Corp.									5b	5b	5b		
6b	Brown University							7u	7u					11u
7b	Brush Development Co.				11u	11u	11u		11u					
8b	Brush Laboratories Co.	20u		8b	7u, 9u	7u		7u			7u			7u
9b	Budd Co.							9b		9b	9b			7u
10b	Bureau of Mines	7u, 10b, 21u	7u, 10b, 21u	10b	10b	10b, 7u	10b, 7u	10b	10b	10b, 7u	10b	10b	7u	10b
1c	California Institute of Technology	7u	20u			7u	20u, 7u	7u	7u					
2c	Carnegie Institute of Technology	20u				3u	3u, 20u	7u						
3c	Case Institute of Technology	7u				7u, 3u	7u	3u, 7u						
4c	Chance-Vought Aircraft Corp.													4c
5c	Chase Brass & Copper Co.		5c	5c		5c, 7u		5c	7u		5c	7u		
6c	Chicago Development Co.	20u	20u			3u								5u
7c	Chrysler Corp.													2u
8c	Cleveland Pneumatic Tool Co.													
9c	Columbia University	20u, 7u				7u	7u	7u						
10c	Consolidated Vultee Aircraft Corp.													3u
11c	Cook Electric Co.										3u	2u		3u
12c	Cornell Aeronautical Laboratory, Inc.						3u	3u						

See footnotes at end of table.

TABLE 62.—Summary of titanium metal and alloys research and development projects in the United States in 1954—Continued

Code No.	Research facility ²	Category being investigated ¹												
		Reduction and chemical thermodynamics	Melting	Chemical analysis	Powder metallurgy	Alloying and its effects	Heat treatment	Mechanical properties	Surface properties and protection	Brazing and welding	Hot and cold shaping	Machining and grinding	Castings	Applications
13c	Crane Co.	13c	13c			13c								
14c	Curtiss-Wright Corp.						2u	14c, 2u	2u	2u	5u, 2u, 14c	2u	2u	2u, 5u
1d	Douglas Aircraft Co.										1d			
2d	Douglas Tool Co.											2d		
3d	Driver-Harris Co.					7u	7u	7u	7u		7u			7u
4d	E. I. du Pont de Nemours & Co., Inc.	4d		4d										
1e	Electro Metallurgical Co.	1e	1e	1e		1e	1e	1e	1e	1e	1e		1e	
2e	Elox Corp. of Michigan											9u		
1f	Fairchild Corp.							2u	2u	2u	2u			
2f	Fansteel Metallurgical Corp.								7u					
3f	Flexonics Corp.													5u
4f	Ford Motor Co.								5u					5u
1g	General Electric Co.		2u	1g			2u	1g, 2u	1g, 2u					2u, 11u
2g	General Motors Corp.						9u	2u	2g	2g, 9u				2u, 9u
3g	Georgia Institute of Technology							7u	7u, 3g					
4g	Goodyear Tire & Rubber Co.										5u	5u		5u
1h	Hamilton-Standard							3u			3u, 9u	9u		9u
2h	Hart Metal Products Corp.													2h
3h	Harvey Machine Co., Inc.										2u, 5u			
4h	Horizons, Inc.	7u, 20u	7u											
5h	Johns Hopkins University					7u				7u				
1i	I-T-E Circuit Breaker Co.													1i
1j	Jacobs Aircraft Engine Co.													1j
1k	Kelsey-Hayes Wheel Co.										5u, 7u	5u, 7u		5u, 7u
2k	Kennecott Copper Co.	2k				2k		2k	2k	2k	5u	2k		5u
3k	Kropp Forge Co.										5u	5u		5u
1L	Arthur D. Little, Inc.	20u												
2L	Lockheed Aircraft Corp.						5u	5u, 2L			2u	2u		5u
1m	P. R. Mallory & Co.			1m										
2m	Mallory-Sharon Titanium, Corp.	2m	2m	2m		2m, 5u, 7u	2m, 7u, 9u	7u, 5u	2m		7u	2m		
3m	Massachusetts Institute of Technology			3m		3m, u		3m, 7u, 6u	6u, 20u		3m			
4m	Menasco Manufacturing Co.		9u					9u						9u
5m	Metal Hydrides, Inc.			5m										
6m	Monsanto Chemical Co.	6m												
1n	National Advisory Commission for Aeronautics							1n						
2n	National Bureau of Standards	2n, 20u						5u	2n		2n			2n
3n	National Lead Co.		3n	3n										
4n	National Research Corp.	4n	7u	4n, 7u		7u, 5u				5u, 7u			4n	
5n	New Jersey Zinc Co.	7u	5n	5n				7u						
6n	New York University	7u, 20u	7u			7u, 9u	5u, 7u, 9u	7u, 9u			7u			
7n	Norris-Thermador Corp.													11u
8n	North American Aviation, Inc.	20u					2u	8n, 2u	8n	2u	2u	8n, 2u		8n, 2u, 5u
1o	Ohio State University	20u					20u	5u, 20u						
1p	Lucius Pitkin, Inc.			7u										
2p	Pratt-Whitney Aircraft					9u	9u	9u			9u	9u		5u, 13u
1r	Rem-Cru Titanium, Inc.		1r	1r		1r, 11u	1r, 11u	1r, 11u, 5u			1r, 11u	1r	7u	11u
2r	Rensselaer Polytechnic Institute	20u						7u		7u				

See footnotes at end of table.

TABLE 62.—Summary of titanium metal and alloys research and development projects in the United States in 1954—Continued

Code No.	Research facility ¹	Category being investigated ¹												
		Reduction and chemical thermodynamics	Melting	Chemical analysis	Powder metallurgy	Alloying and its effects	Heat treatment	Mechanical properties	Surface properties and protection	Brazing and welding	Hot and cold shaping	Machining and grinding	Castings	Applications
3r	Republic Aviation Corp.							<u>3u</u>	<u>3u</u>	<u>3u</u>				
4r	Republic Steel Corp.		3r			3r					3r			3r
5r	Ryan Aeronautical Co.							<u>9u</u>						<u>9u</u>
1s	A. O. Smith Corp.			1s			<u>3u</u>		<u>3u</u>	<u>3u, 7u</u>	<u>3u</u>	<u>3u</u>		<u>5u</u>
2s	Solar Aircraft Co.													
3s	Southern Research Institute							<u>3u</u>						
4s	Spectrochemical Laboratories			<u>3u</u>										
5s	Steel Improvement & Forge Co.										5s			
6s	Superior Tube Co.										6s			6s
7s	Surface Combustion Corp.													<u>5u</u>
8s	Sylvania Electric Products							<u>3u</u>						
9s	Syracuse University					<u>3u</u>		<u>3u</u>						
1t	Taylor Forge & Pipe Works													
2t	Temco Aircraft Corp.										2t			
3t	Titanium Metals Corp. of America	<u>7u, 3t</u>	<u>7u, 3t</u>	<u>7u, 3t</u>	3t	<u>7u, 3t</u>	<u>7u, 3t</u>	<u>7u, 3t</u>	3t	3t	3t	3t	3t	3t
4t	Sam Tour & Co., Inc.			<u>7u</u>										
1u	Union Carbide & Carbon, U. S. Air Force:	1u								1u				
2u	Air Materiel Command													
3u	Air Research & Development Command													
4u	U. S. Army:													
5u	Army Ordnance Corps, Detroit Arsenal													4u
6u	Frankford Arsenal			6u				6u	6u					6u
7u	Watertown Arsenal	<u>7u</u>	<u>7u</u>	<u>7u</u>		<u>7u</u>	<u>7u</u>	<u>7u</u>	<u>7u</u>	<u>7u</u>	<u>7u</u>	<u>7u</u>		<u>7u</u>
8u	Watervliet Arsenal													8u
9u	U. S. Navy:													
10u	Bureau of Aeronautics, Naval Air Materiel Center					9u	9u	9u		9u	9u			9u
11u	Bureau of Ordnance, Naval Gun Factory							11u			11u			11u
12u	Naval Ordnance Laboratory					7u					7u			
14u	Picatinny Arsenal			7u										
15u	U. S. Naval Proving Grounds			15u				15u						15u
16u	Bureau of Ships:													
17u	Boston Naval Shipyard										16u			
18u	Engineering Experiment Station			16u		16u		16u	16u		16u			16u
19u	Industrial Testing Laboratory							16u			16u			16u
20u	Naval Research Laboratory	20u		20u				20u						20u
21u	Office of Naval Research													
23u	University of California					21u		21u						
24u	University of Connecticut						7u							
25u	University of Illinois							1g, 2w						
26u	University of Kentucky							3u	3u					
27u	University of Michigan			7u								7u		
1w	Weatherhead Co.													9u
2w	Western Cartridge Co.													
3w	Westinghouse Electric Corp.													9u
4w	Wisconsin Centrifugal Foundry, Inc.												4w	
5w	Worcester Pressed Steel Co.										7u			7u
6w	Wyandotte Chemical Corp.								7u					
7w	Wyman-Gordon Co.										7w			

¹ Coded numbers in columns indicate research sponsor; underlined numbers in italics indicate Government sponsorship.

² Those organizations that have blank spaces in every category are solely project sponsors.

SOURCE: Air Materiel Command of the U. S. Air Force, Titanium and Titanium Alloys Programs: Books 1-5, Wright-Patterson Air Force Base, Ohio, 1955.

CHAPTER 12. SELF-SUFFICIENCY AND POLITICAL CONTROL

SELF-SUFFICIENCY

MINERALS

The situation of the United States has changed radically in the past 15 years as a result of the exploration, development, and expansion of domestic titanium properties. In 1952-55 about two-thirds of the supply of rutile needed to produce titanium metal was imported from Australia. If necessary, ilmenite, titanium slag, or manufactured titanium dioxide could be substituted at extra cost in virtually all applications of rutile, and the remaining needs could be supplied by domestic rutile producers. The United States is the world's largest producer of ilmenite.

The titanium-mineral self-sufficiency of the United States in past years may be arrived at by dividing domestic production (TiO_2 content) by consumption (TiO_2 content) of ilmenite or rutile. The self-sufficiency of the United States in ilmenite and rutile since 1941 is shown in table 63. Imports from Canada have been added to domestic production to give some idea of the self-sufficiency of the North American Continent.

TABLE 63.—*Portion of domestic consumption of titanium minerals supplied by domestic production and imports from Canada, 1941-54, in percent*

Year	Consumption supplied by domestic production		Consumption supplied by imports from Canada: Ilmenite	Consumption supplied by domestic production plus imports from Canada: Ilmenite
	Rutile	Ilmenite		
1941.....	49	7	2	9
1942.....	25	24	1	25
1943.....	23	63	18	81
1944.....	47	72	7	79
1945.....	74	76	2	78
1946.....	105	64	<1	65
1947.....	113	63	1	64
1948.....	72	59	<1	60
1949.....	59	72	1	73
1950.....	64	68	<1	69
1951.....	42	74	<1	75
1952.....	39	1 74	1 8	1 81
1953.....	34	1 64	1 24	1 88
1954.....	35	1 66	1 18	1 84
1955.....				
1956.....				
1957.....				

¹ Calculations include consumption of titanium slag.

² Calculations include consumption and imports of titanium slag.

The figures indicate that the United States has become increasingly dependent upon imports to supply domestic needs of rutile, whereas for ilmenite, approximately the same ratio of production to consumption has been maintained from 1943 to 1954.

If the United States were cut off from imports and were to become 100-percent self-sufficient, the number of years of self-sufficiency might be estimated by dividing the reserves of TiO_2 by the current consumption. The Federal Geological Survey estimates the TiO_2 content of domestic rutile reserves to be a minimum of 769,000 short tons. This quantity, divided by a 1954 consumption rate of 20,000 short tons, seems to indicate that the United States could be self-sufficient for 38 years. Indications are, however, that in the near future rutile consumption in the United States will double that in 1954, and it is unlikely that the United States could become self-sufficient in rutile, unless the needs for titanium metal were met by substituting ilmenite or titanium slag.

The number of years of self-sufficiency in ilmenite may similarly be derived by dividing the TiO_2 content of the minimum domestic ilmenite reserves, 26,027,000 short tons, by the 1954 consumption of 424,300 short tons of ilmenite and slag. This yields a figure of 61 years as the minimum number of years of ilmenite self-sufficiency. The maximum recoverable ilmenite reserve figure of 40,647,000 short tons, developed by the Geological Survey, indicates a self-sufficiency for 96 years at 1954 consumption rates. In addition to these domestic reserves, Canada has a minimum reserve of 36,321,000 tons of TiO_2 in the form of recoverable ilmenite, most of which probably will be available to the United States.

United States might become self-sufficient in ilmenite but probably will become increasingly dependent upon Australian deposits for rutile. The deposit being developed at Oaxaca, Mexico, may eventually play an important part in furnishing rutile for the expanding metal industry and may help alleviate the rutile shortage.

In a national emergency, it probably will be necessary for the titanium-metal industry to chlorinate ilmenite or titanium slag. Some of the companies doing experimental work on the chlorination of slag estimate that it would

take less than a year to convert their facilities so that they could use slag or ilmenite instead of rutile if the additional operating costs were ignored; however, the use of ilmenite or slag would also present a number of technological problems.

If the price of rutile continues to rise, it may become economically feasible to switch to slag or ilmenite as a source material for titanium tetrachloride because of the relatively low initial cost of these materials. In that event the North American Continent could become self-sufficient in titaniferous material.

RAW MATERIALS FOR METAL

Other raw materials needed for producing titanium sponge by the Kroll process include magnesium, chlorine, electrical energy, inert gas (helium or argon), and fuel. Major requirements per pound of sponge are 2 to 2.8 pounds of TiO_2 , 5 pounds of chlorine, 1.25 pounds of magnesium, and 0.9 cubic foot of inert gas. If the magnesium and chlorine are regenerated, the requirement for magnesium is about 0.2 pound and for chlorine about 1 pound.

Power requirements vary within the industry and may range from 5–20 kw.-hr. per pound of sponge, depending upon the extent of operations in a particular plant. The Bureau of Mines, in its operations at Boulder City, Nev., consumed 4.7 kw.-hr. of electricity per pound of sponge produced, 3.2 kw.-hr. alone being used in the vacuum-distillation units. The furnaces were heated with gas, and the Bureau did not manufacture its own titanium tetrachloride or recycle the magnesium chloride produced.

If the magnesium chloride had been recycled, power consumption for this operation would have been at least 10 kw.-hr. per pound of magnesium produced. Any new magnesium that must be purchased to make up for losses in the recycling process also represents 10 kw.-hr. of power per pound. Power consumption could be cut somewhat if the sponge were purified by leaching rather than vacuum distillation. Electric power consumption would also be greater if the furnaces were heated by electricity rather than by gas.

In the latter part of 1954 an official of the Titanium Metals Corp. of America estimated that his company used 15 kw.-hr. of electricity per pound of sponge. This company recycles some of its magnesium chloride and manufactures its own titanium tetrachloride but does not make its own chlorine. The official estimated further that about 20 kw.-hr. is required per pound of sponge if the power that went into new magnesium and chlorine is taken into account. This is a large amount of power when compared with the 8 kw.-hr. needed to produce 1 pound of aluminum.

This discussion shows that a major consideration in expansion of the titanium industry is availability of electric power. Aside from the production of sponge, power is also needed in smelting ilmenite to make titaniferous slag and in melting sponge to produce ingots. In Bureau of Mines experiments about 2,200 to 2,900 kw.-hr. was required to produce 1 ton of titanium slag from ilmenite. The slag made in this work contained over 80 percent TiO_2 .

One company requires 2.0–2.5 kw.-hr. to melt 1 pound of titanium sponge, employing double-melting techniques.

Most other raw materials needed in producing titanium sponge are in plentiful supply. A shortage of helium developed early in 1955, making it necessary for some sponge producers to partly substitute argon for helium. The use of argon is technically possible but involves many problems to the user. E. I. du Pont de Nemours & Co., Inc., seems to have minimized these problems, as it uses only argon in its titanium operations.

POLITICAL CONTROL

Tables 64 and 65 show the political control of recoverable deposits of rutile and ilmenite. As indicated in chapter 3, these reserve estimates are subject to the following qualifica-

TABLE 64.—*Political control of recoverable rutile reserves*

Country	Contained TiO_2 , short tons	Percent of world total	Percent of major producing countries
Australia.....	2,554,000	25.0	76.9
India.....	1,900,000	18.6	
Mexico.....	4,812,000	47.2	
Union of South Africa.....	167,000	1.6	
United States.....	1,769,000	7.6	23.1
Total.....	10,202,000	100.0	100.0

¹ Minimum reserve from table 21.

TABLE 65.—*Political control of recoverable ilmenite reserves*

Country	Contained TiO_2 , short tons	Percent of world total	Percent of major producing countries
Australia.....	2,230,000	1.7	
Canada.....	36,321,000	27.1	27.8
Egypt.....	3,855,000	2.9	2.9
Finland.....	6,750,000	5.0	5.2
India.....	30,000,000	22.3	22.9
Japan.....	3,539,000	2.6	2.7
Norway.....	24,361,000	18.2	18.6
Union of South Africa.....	1,100,000	.8	
United States.....	26,027,000	19.4	19.9
Total.....	134,183,000	100.0	100.0

¹ Minimum reserves from table 24.

² Minimum reserves from table 22.

tions: (1) Many estimates are inferred; (2) reserve data are lacking for some of the large deposits, especially in the U. S. S. R.; (3) not all of the contained titanium in a given deposit may be recoverable.

According to published data of the major rutile producers, Australia contains 76.9 percent of the reserves currently being mined, and the United States contains the remaining 23.1 percent. India and Mexico are potential producers of rutile because of their large reserves; but production from India has been negligible as of 1955, and no rutile has as yet been mined

in Mexico. There are no indications that rutile is mined in Russia or in any of the Communist bloc of nations.

Of the total reserves of the major ilmenite-producing countries, the United States contains 19.9 percent of the total, Canada has 27.8 percent, and India has 22.9 percent. None of the countries listed in table 65 is a member of the Communist bloc, and it is not possible to estimate from published data what quantity of ilmenite reserves might occur in these countries. Russia has large reserves of titaniferous magnetite that may or may not be mined at present.

CHAPTER 13. PUBLIC POLICY AND NATIONAL DEFENSE

MOBILIZATION EXPERIENCE IN WORLD WAR II, 1941-45

ALLOCATION PROGRAM

ORES

After the outbreak of war in Europe in 1939, demands for welding rods, titanium pigments, and alloys, supported in large part by defense spending, quickly rose to record heights. In late 1940 a foreign procurement program was initiated by the Metals Reserve Company, and rutile was included in an agreement with Brazil under which the United States was to purchase the entire exportable surplus of 10 commodities. Similar agreements with other Latin American countries made available virtually the entire exportable mineral output of Latin America. Valuable shipments of Brazilian rutile were made during World War II under this program.

Shipping shortages prevented continuation of large imports of ilmenite from India, and in 1942-43 Canada superseded India as our chief foreign supplier. Rutile imports from Australia were sustained to a considerable extent, as space was often available on vessels returning from delivery of military supplies. Control over imports was necessary under these circumstances to direct the distribution of imported titanium minerals in the domestic economy. Rutile was put under import control by the Office of Production Management on December 26, 1941 (Order M-63).

It was not considered necessary to put rutile under direct allocation controls because the production and use of welding rods and the production of ferrotitanium and titanium cyanonitride were controlled. However, dealers were verbally requested by the War Production Board in the spring of 1942 to divert to welding-rod and alloy producers the quantities of rutile normally moving to ceramic manufacturers, although no formal order to that effect was promulgated. It was not necessary to allocate ilmenite, because an adequate supply had been developed by 1943.

PIGMENTS

The Office of Production Management established an allocation program for titanium pigments on November 27, 1941, issuing General Preference Order M-44. On January 24,

1942, an amendment to M-44 raised the pool to be set aside by producers of pigments for allocation from 20 percent, as provided in the order, to 25 percent. In the latter half of 1942 only a fraction of the raw-material supply and production capacity was actually required for the war effort, and M-44 was revoked on December 8, 1942.

The increasing demand for titanium pigments during 1943 resulted in complaints by civilian users of their inability to obtain delivery on orders. A War Production Board conservation order designated as M-353 was issued December 6, 1943. Although the order did not make any more pigment available for civilian use, it regulated distribution of the commodity. After military orders had been filled, the order provided for sales to civilian users on their unrated orders by producers and other suppliers on the basis of past experience.

Although a specific expiration date was included in the original order, this was deleted February 29, 1944. The order was amended December 24, 1943, to include barium- and calcium-base extended titanium pigments and titanated lithopone. It was revoked March 26, 1945.

General Preference Order M-340, which allowed the War Production Board to designate the specific uses for chemicals and the users to which they would be delivered, was simultaneously amended to apply to titanium dioxide when Order M-353 was revoked. The order, M-340, was revoked September 30, 1945.

PRICE CONTROLS

ORES

On April 28, 1942, the Office of Price Administration issued the General Maximum Price Regulation, which provided that the maximum price for any commodity not then under specific regulation should be the highest price charged by the seller on a delivery of that commodity during March 1942 to a purchaser of the same class. Metalliferous ores and concentrates were specifically exempted from the regulation, but rutile and ilmenite were not classified as metalliferous.

To provide a regulation adapted to the special problems in connection with a number of non-metallic minerals, including ilmenite and rutile, the Office of Price Administration issued Maximum Price Regulation 327. The regulation,

which became effective February 22, 1943, removed these commodities from the control of the General Maximum Price Regulation.

The new regulation retained the essential features of the older one, including the adjustment provision that had recently been written into the General Maximum Price Regulation for essential commodities. This permitted granting relief to producers unable to maintain or expand production under existing maximum prices in case of a general shortage in the supply of an essential commodity or when loss of the seller's production would result in higher prices to consumers.

In addition, MPR 327 provided that, if a seller offered a new grade or type of the same mineral, he had to submit his proposed price for such new grade or type for the approval of the Office of Price Administration. The new price was to be determined whenever possible by the method of pricing used by the seller during March 1942.

The maximum price of any product offered for sale for the first time after February 22, 1943, was to be approved by the Office of Price Administration. Prices set by the seller without approval in either of the above instances were subject to refunds if the Office of Price Administration adjusted the proposed prices downward. Ilmenite and rutile prices were decontrolled on July 26, 1946 (Amendment 36, Supplementary Order 129, to the General Maximum Price Regulation).

PIGMENTS

To avert a proposed price increase for titanium pigments, the Office of Price Administration, January 3, 1942, requested the stabilization of prices at those of October 1, 1941. January 24, 1942, the American Zirconium Corp. was permitted to add 1½ cents a pound to these prices because of the high cost of production.⁷ The corporation was at that time developing a new source of ilmenite in North Carolina. It was believed that this additional supply could be obtained by May 2, 1942, at a cost that would permit the corporation to sell titanium dioxide within the ceiling.

Price Schedule 98, issued February 5, 1942, established maximum prices for titanium pigments. Subsequent amendments to the schedule permitted deliveries to be made on open invoice after special permission had been obtained from the Office of Price Administration. Buyers and sellers could thus make long-term contracts and agree to fix prices, no higher than the maximum prices then in effect, at the time of delivery. The American Zirconium

Corp. was allowed to charge the higher price throughout the life of the schedule, which was terminated in November 1945.

GOVERNMENT STOCKS OF ORE

Government purchasing of rutile was begun in 1941, when the Metals Reserve Company made a commitment to buy it. By the end of 1941 the Government had obtained 31 short tons of rutile. The amount of Government stocks varied from year to year, reaching a peak in 1945, when 3,891 short tons was reported at the end of the year. The objective of Government purchases was to accumulate a 6-month reserve of rutile at the then current rate of consumption, but this goal was not reached during the war. The last year in which Government stocks were reported was 1946, when 3,891 short tons was on hand. Most of this material was presumably transferred to the National Strategic Stockpile in 1946.

No attempt was made to purchase ilmenite because of the availability of supplies from both Canada and domestic sources.

DEVELOPMENT OF NEW SOURCES OF ORE

Virtual cessation of ilmenite imports in 1942 necessitated development of a new domestic source of supply. Discussion between representatives of the Office of Production Management, the Office of Price Administration and Civilian Supply, and all manufacturers of titanium pigments in August 1941 resulted in the following plan: (1) That an ore deposit at Sanford Lake, N. Y., already being developed by the National Lead Co. for its own requirements, should also be made available to other users of ilmenite; (2) that the National Lead Co. install additional units at Sanford Lake and allocate the output of these units to companies desiring to participate in the project, the participating companies to pay their proportional share of the cost of thus adding to the productive capacity of the mine, plus the cost of extraction, treatment, and transportation of the ore; (3) that the National Lead Co. make no additional charge, other than a nominal 20 cents per ton of concentrate, for depletion of ore reserves; (4) that all participants in the program and the Office of Production Management and the United States Department of Justice have the right to audit the books of the National Lead Co., showing the costs of equipment and costs of extraction, maintenance, and taxes; and (5) that each participant have the right to suspend or discontinue receipts of ore. The participant would have to continue to pay its share of the cost of development unless the capacity was otherwise used.

⁷ In 1939 the State of Maryland compelled the corporation to install an acid-recovery unit, which cost approximately \$300,000 and added to the cost of production. The corporation also experienced difficulty in handling domestic ores and reworking materials to eliminate foreign matter.

The Krebs Pigment and Chemical Division, E. I. du Pont de Nemours & Co., Inc., accepted a 25-percent interest in the project on October 2, 1941. The agreement was to last for 10 years from the date of completion of the additional capacity (October 5, 1942). By August 1942 the mine, known as the MacIntyre development, had started production. Ultimate capacity was 26,000 short tons of ilmenite concentrate, equal to about 12,000 tons of titanium dioxide per month, 25 percent of which went to Du Pont. This, combined with other North American sources, insured enough raw material for the pigments branch of the industry. (The domestic production capacity at that time totaled 12,300 short tons of titanium pigments per month.)

The Defense Plant Corporation offered a 5-year contract on July 6, 1942, to the National Lead Co. to provide a 33-mile rail line connecting Tahawus, N. Y., with the Delaware & Hudson railhead at North Creek, N. Y. Under the proposed contract the Defense Plant Corporation was to advance \$3,208,575 to the company, covering construction and other necessary costs. This offer was accepted, and the railroad was completed in June 1944.

Agreements between the Defense Plant Corporation, National Lead Co., and Delaware & Hudson Railroad Corp. permitted National Lead to lease the railroad from the United States Government. The Delaware & Hudson Railroad Corp. operated the line for transporting ilmenite, magnetite, and supplies between Tahawus and North Creek. National Lead Co. paid the Government a rental fee, based on a fixed charge per ton for all commodities transported over this Government-owned railroad line.

The ilmenite situation was further relieved in 1944 and 1945 by the receipt of greatly increased supplies from India, increased shipping facilities having been made available during these years.

PRIORITIES FOR PIGMENT FACILITIES

Titanium dioxide was one of the selected group of materials listed on April 4, 1946, by the Civilian Production Administration for inclusion in Schedule 1 of Priorities Regulation 28. Manufacturers of titanium pigments were assigned CC ratings, highest obtainable for civilian goods, to enable them to expand capacity 20 percent by late 1946. Du Pont, American Cyanamid, and National Lead began expansion programs but ran into difficulties because of the flood of orders facing equipment manufacturers and the shortage of raw materials.

The regulation provided for issuing "urgency certificates" to all companies producing titanium

dioxide, giving them preference over other classes of buyers, if producers demonstrated their need for titanium ores to sustain or increase production. The National Paint, Varnish, and Lacquer Association had stated in December 1945 that the shortage of titanium pigments was a contributing factor in preventing the industry from utilizing its full productive capacity. Manufacturers of building materials and other "critically scarce products" using titanium were granted a top priority for obtaining surplus materials held by the War Assets Administration.

DEFENSE EXPERIENCE, 1950 TO MID-1955

ALLOCATION PROGRAM

Regulation 1, issued by the National Production Authority (NPA) September 18, 1950, placed controls on inventories of scarce materials. As amended October 22, 1951, titanium sponge, semifabricated shapes, sheets, tubes, extrusions, alloys, and scrap were controlled by this regulation. The regulation prevented the accumulation of excessive inventories by limiting the quantity of such materials that could be ordered, received, or delivered to a consumer. This regulation was revoked, effective May 1, 1953.

Another NPA order that closely paralleled Regulation 1 was the Designation of Scarce Materials 1 (DSM-1) issued December 27, 1950. This order specifically listed scarce materials that were not to be hoarded. By the amendment of November 7, 1951, DSM-1 listed certain titanium products, namely sponge, tubes, extrusions, titanium-bearing alloys, titanium-base alloys, and scrap. These products were removed from this status by the amendment of June 18, 1953, but were reinstated in Schedule A of Defense Production Order 1, Supplement 1, July 13, 1953.

The use and inventory of ferrotitanium and other alloying materials for steel were regulated by NPA Order M-80, issued August 17, 1951.

Basic rules of the priorities system authorized under section 101 of the Defense Production Act of 1950 were announced by the National Production Authority October 3, 1950, in Controlled Materials Plan (CMP) Regulation 2. December 18, 1950, NPA delegated its authority to regulate the allocations and priorities of some commodities to the United States Department of the Interior by NPA Delegation 5. Commodities in this delegation included titaniferous ores, titanium-metal sponge, chips, and powder.

An amendment to NPA Delegation 5 on January 29, 1952, similarly delegated authority to the Defense Materials Procurement Admin-

istration to allocate rutile and other titanium ores and concentrates. It also gave claimant authority to DMPA over titanium-ore mining, ore concentration, and plants for producing sponge.

MO-1, issued by the Defense Minerals Administration of the United States Department of the Interior, December 29, 1950, designated various materials as scarce. In substance this order paralleled National Production Authority DSM-1 but included titaniferous ores, as well as titanium-metal sponge, chips, and powder. MO-1 was revoked as of March 12, 1953.

The duties of the National Production Authority were taken over by the Business and Defense Services Administration in October 1953. BDSA issued Notice 1 and Schedule A, placing controls on the general distribution of titanium sponge and titanium metal (ingot and mill products), November 18, 1953.

In early 1953 E. I. du Pont de Nemours & Co., Inc., voluntarily allocated its output to three major fabricators—Rem-Cru Titanium, Inc., Mallory-Sharon Titanium Corp., and Republic Steel Co.—on the basis of its 1952 sales. The entire output of the Titanium Metals Corp. of America was fabricated by Allegheny-Ludlum, one of its two parent companies. Before Notice 1 and Schedule A were issued, NPA had unofficially allotted Mallory-Sharon Titanium Corp. and Republic Steel Corp. a certain percentage of the sponge produced by the Federal Bureau of Mines. This scheduling by NPA had begun in July 1953, and Notice 1 and Schedule A formally defined the powers of BDSA in scheduling mill-product shipments.

Because no industry can survive when it depends solely upon defense orders, it was decided to permit the various semifabricators to contract with regular commercial customers for the delivery of titanium-mill products. BDSA Order M-107, dated May 19, 1954, provided that no producer of titanium-mill products would be required to accept rated (military) orders calling for delivery in any calendar month exceeding 90 percent of his scheduled production. The 10 percent set aside for civilian consumption permitted producers to explore industrial markets with some assurance of making delivery of titanium-mill products.

Another function of Order M-107, which was still in effect in June 1955, was to set up a co-operative working arrangement between BDSA and the United States Department of Defense for establishing priorities for titanium-mill products. Under the order producers of mill products are required by the 15th of each month to furnish in writing to the Aircraft Production Resources Agency (APRA), Wright-Patterson Air Force Base, Dayton, Ohio, detailed schedules of their projected production of titanium-

mill products pursuant to rated orders for delivery during the coming month and each 2 succeeding months. APRA transmits each producer's schedule to the United States Department of Defense, Washington 25, D. C., with APRA'S recommendations. The department transmits each producer's schedule to BDSA, with its recommendations, not later than 7 days before the end of the first month shown on such schedule. BDSA reviews such schedules, with the United States Department of Defense recommendations, and issues to each producer, not later than 3 days before the end of the first month shown on such schedule, a directive covering his production of titanium-mill products to fill rated orders during the 2 succeeding months.

The 10 percent set aside for civilian consumption is not scheduled by Government agencies.

Before Order M-107 was issued, requests for delivery of titanium-mill products abroad were made through the Foreign Operations Administration and scheduled by BDSA after a defense rating had been obtained from the Department of Defense. A defense rating was no longer required after May 1954, as export orders were included under the 10 percent to be allocated to civilian consumers.

PRICE CONTROLS

The General Ceiling Price Regulation (16 FR 808), originally issued by the Office of Price Stabilization January 26, 1951, held the price of rutile to a ceiling based on prices in effect from December 19, 1950, through January 25, 1951. The effect of this regulation was to stabilize the price of rutile at \$100 per ton, f. o. b. east coast. Increased world demand for Australian rutile raised the price to such an extent that United States concerns could not negotiate for rutile because the ceiling price was frozen much lower.

General Overriding Regulation 9, Amendment 13, of the Office of Price Stabilization, effective January 18, 1952, exempted from price controls all sales of imported and domestic rutile ores and concentrates and the allied services of mining and processing such materials. Rutile was removed from price control to permit domestic consumers and dealers to compete with those of other countries in obtaining this material and to encourage domestic miners to continue production.

Industry stocks of rutile had declined from 8,329 short tons in 1950 to 6,395 in 1951, but after the overriding regulation was issued they rose in 1952 to 13,815 short tons. Prices reached \$140 to \$170 per ton but within a year had fallen to \$100 to \$120 per ton, f. o. b. east coast.

EXPANSION GOALS

METAL

The President was empowered to issue contracts for expansion of productive capacity and supply by section 301 of the Defense Production Act of 1950. Government aid in defense exploration projects involving a variety of minerals was authorized in section 303 of the act. Negotiation of contracts for primary titanium metal and their administration as regards inspection, delivery, purchase, storage, and payment for production was delegated by executive order to the Defense Materials Procurement Agency August 28, 1951. This authority was vested in the Expansion Branch, Emergency Procurement Service, General Services Administration, August 15, 1953, by Executive Order 10480.

The Government-sponsored expansion program for basic titanium-metal production is premised on the assumption that expansion of production facilities by private industry, based on past experience with new materials, will take considerable time. Consumption has been confined almost exclusively to military items, and estimates of requirements are based almost entirely on military considerations.

Expansion goals for rutile, titanium pigments, and titanium sponge were issued and periodically revised by civilian agencies. Changes in the goal for titanium sponge are summarized in table 66.

TABLE 66.—*Expansion goals for titanium sponge*

Date	Issuing agency	Goal
March 1951-----	Defense Production Administration.	7,200 short tons (no goal date specified).
June 20, 1952----	-----do-----	10,000 short tons by 1955.
Oct. 13, 1952----	-----do-----	22,000 short tons by 1955.
Aug. 6, 1953----	Office of Defense Mobilization.	25,000 short tons by 1956.

At the end of 1954 the Government negotiated with all potential domestic producers prepared to enter the titanium-sponge-production field, irrespective of the 25,000-ton figure. Such proposals were considered for specific approval in the light of facts and conditions prevailing at the time. In proceeding in this fashion, it was contemplated that the 25,000-ton figure might be exceeded, but a ceiling was placed officially on the additional facilities to which the Government was prepared to lend financial assistance.

MELTING AND PROCESSING FACILITIES

On February 10, 1954, the Office of Defense Mobilization established an interim expansion goal of 37,500 short tons for titanium-melting facilities to be reached by 1956. The industry had at that time a melting capacity of approximately 7,680 tons per year. August 17, 1954, an interim expansion goal for titanium-processing facilities was announced by the Government, calling for an industry annual capacity by the end of 1956 to process 37,500 tons of titanium ingot into mill products.

ORES

September 18, 1952, Defense Production Administration established an expansion goal of 25,000 short tons of rutile in 1954, calling for an increase of 16,000 tons over the 1951 domestic production.

PIGMENTS

March 10, 1952, DPA established a goal of 370,000 short tons of titanium pigments per year by January 1, 1954, an increase of 88,000 tons over domestic pigment capacity in 1950. Tax amortization certificates were issued to assist in the construction of added pigment facilities.

IMPLEMENTATION OF EXPANSION GOALS

To increase production of titanium metal the Government has provided assistance to producers along the following lines: (1) Loans to construct plants; (2) procurement contracts; (3) accelerated tax amortization; (4) purchases in times of excess supply for a temporary Government working inventory; (5) loans for pilot plants; (6) showing contractors all steps in production at the Bureau of Mines pilot plant at Boulder City, Nev. A further aid to industry took the form of Government-sponsored research and development projects. Information gained from these projects was made available to the titanium industry. This program is discussed in detail in Chapter 11. Government Programs.

These aids to the titanium industry differ markedly from the Government program to effect expansion of industry in general in World War II. During World War II direct Federal investment dominated the facilities-expansion program, accounting for \$17 billion of the total of over \$23 billion expended to expand the manufacturing industries. Private expansion was pressed, but it was confined predominantly to less risky types of facilities, generally those similar to regular peacetime production pat-

terms of the particular industry. The Federal Government investment was, on the other hand, concentrated in munitions-type plants or facilities to produce new or untested products.

GOVERNMENT CONTRACTS

The Government contracted with industrial concerns on an individual basis for additional plant capacity in amounts commensurate with the technical experience and financial ability of each contractor. Proposals received by the Government were reviewed and passed on by a technical committee, acting on a confidential basis, of the National Research Council.

Under the Government expansion program, five contracts pertaining to the production of titanium metal were signed between General Services Administration, representing the Government, and industry by mid-1955. The latest contract, signed in 1954, brought the total planned titanium-sponge capacity to 22,500 tons per year. Of this total, Government contracts called for an annual output of 21,600 tons by 1957. Du Pont had additional capacity for producing 900 tons per year, independent of Government contract. The terms of these agreements are condensed in table 67 and may be summarized as follows:

TITANIUM METALS CORP. OF AMERICA

Titanium Metals Corp. of America signed a letter agreement on August 1, 1951, for construction and operation of a plant at the Government's former Basic Magnesium, Inc., plant, Henderson, Nev., to produce 3,600 short tons of titanium sponge metal a year for 5 years. An advance of \$15 million was made to TMCA by the Government. This advance, plus interest at 4 percent a year on the unpaid balance, was repayable either in dollars or in titanium metal. Commencing with the date when the plant was capable of producing approximately 1,800 tons of titanium a year and continuing thereafter until termination or completion of the contract (termination date, August 1, 1961), TMCA was required to sell to the Government, or for its account, all or any part of 100 tons of titanium in sponge or ingot form during each 3-month period. Major components of the plant were leased from the State of Nevada. Power was allocated from Hoover and Davis Dams, up to a maximum of 151 million kw.-hr., by the Colorado River Commission from the quota allotted to the State of Nevada. The Henderson plant, the first fully integrated titanium plant with facilities for chlorination of titanium ore and recovery of magnesium and chlorine by electrolysis of magnesium chloride, began commer-

TABLE 67.—Summary of Government titanium-production contracts in force as of June 1955

	Contractors				
	Titanium Metals Corp. of America	E. I. du Pont de Nemours & Co., Inc.	Cramet, Inc.	Dow Chemical Co.	Electro Metallurgical Co.
Date signed.....	8/1/51	7/24/52	7/31/53	7/8/54	9/14/54
Plant location.....	(¹)	(²)	(³)	(⁴)	(⁵)
Planned annual capacity, short tons under contract.....	3, 600	2, 700	6, 000	1, 800	7, 500
Government loan.....	\$15, 000, 000	\$14, 700, 000	\$24, 950, 000		
Tax-amortization rate, percent.....	90	90	90		90
Titanium-sponge specifications, percent:					
Titanium (min.).....	99. 3	99. 3	99. 5	99. 3	Balance
Iron (max.).....	. 25	. 25	. 15	. 15	0. 20
Nitrogen (max.).....	. 03	. 03	. 03	. 03	. 03
Chlorine (max.).....		. 15	. 12	. 15	. 30
Magnesium (max.).....		. 10	. 07	. 07	(sodium) . 05
Carbon (max.).....		. 05	. 05	. 07	. 06
Total impurities (max.).....	. 70	. 70	. 50	. 70	(⁶)
Brinell hardness No.....	225	203	170	160	160
Repayment of Government loan, poundage payment, per pound produced.....	\$0. 47	\$0. 61	\$0. 52		
Contract termination date.....	8/1/61	6/30/62	1/31/61	7/1/61	6/30/63

¹ Henderson, Nev.

² Newport, Del.

³ Chattanooga, Tenn.

⁴ Midland, Mich.

⁵ Ashtabula, Ohio.

⁶ Total metals, other than those listed, not to exceed 0.25 percent; nor is any single element to exceed 0.10 percent.

cial production of titanium sponge in October 1951, with a target of 3,600 tons of titanium sponge by 1953. This capacity goal was later extended to 1954.

E. I. DU PONT DE NEMOURS & CO., INC.

E. I. du Pont de Nemours & Co., Inc., concluded the second major agreement in the Government-industry program to increase titanium sponge-metal production July 24, 1952. The Government agreed to advance the company up to \$14.7 million to expand its titanium-producing facilities at Newport and Edge Moor, Del. The loan was to be repaid with interest (4 percent) as salable titanium sponge was produced. The contract called for the production of 13,500 short tons of titanium sponge in addition to the company private output of 4,500 tons over a 5-year period. Beginning with the date when the additional facilities were capable of producing approximately 1,350 tons of titanium annually and continuing thereafter until termination or completion of the contract (termination date, June 30, 1962), the Administrator (Government) had the right to require the company to sell to the Government, or for its account, all or any part of the first 75 tons of such titanium sponge metal produced from the additional facilities by the contractor thereafter during any calendar quarter.

FEDERAL BUREAU OF MINES

The Federal Bureau of Mines was requested to enter into an agreement (signed April 30, 1953) with the Defense Materials Procurement Agency for production of titanium sponge at the Bureau pilot plant, Boulder City, Nev. The contract was negotiated owing to the shortage and the anticipated future insufficiency of titanium metal for national defense. Under the contract the Bureau of Mines was to produce, within 18 months following the effective date of the agreement, a minimum of 180 short tons and a maximum of 250 tons of usable ductile titanium at a minimum rate of 1,000 pounds and an optimum rate of 1,400 pounds daily. Funds were to be advanced to the Bureau, based on production costs not to exceed a maximum of \$2,250,000. Bureau of Mines production of acceptable titanium sponge under the contract totaled 246 tons. Bureau production (which ceased September 7, 1954, about 2 months before the contract's termination date, October 31, 1954) was to supplement but not compete with private production.

The agreement permitted minor capital improvements and equipment alterations designed to decrease production cost, enabled the Bureau to obtain a more accurate cost evaluation of titanium-production processes, and facilitated certain phases of the research program that required continuous plant operations.

CRAMET, INC.

Cramet, Inc. (a wholly owned subsidiary of Crane Co.), signed a contract with the Government on July 31, 1953, for constructing and operating a plant with a capacity of 6,000 short tons of titanium sponge annually. The new facility, which is at Chattanooga, Tenn., was scheduled to begin partial production by early 1955. The Government agreed to advance the company up to \$24,950,000 for construction and equipment costs, to be repaid with interest (5 percent a year) on the unpaid balance from the date of the advance. The Government had an option to buy up to 7,500 tons of titanium sponge during the term of the contract at \$5 per pound for any sponge bought during the first year of production and \$4 per pound or market price, whichever was greater, thereafter. On the other hand, the company could require that the Government buy up to 6,000 tons of sponge during the life of the contract at \$5 per pound during the first year of production (not to exceed 1,000 tons) and \$4 per pound thereafter. The contract was to expire 7½ years from the date of execution.

DOW CHEMICAL CO.

The Dow Chemical Co., Midland, Mich., contract (DMP-99), signed July 8, 1954, called for expansion of the company 1954 titanium experimental facility rated at 600 pounds per day to 1 to 1½ short tons per day by January 1, 1956, and 5 tons per day by July 1956. The company employs a magnesium-reduction process in producing titanium sponge. GSA will purchase under the contract, if the company does not find other markets, a maximum of 2 million pounds of titanium produced before July 1956. The material will be bought at market price for the first 6,000 pounds in any month and the balance at \$5 per pound or at the lowest figure at which the company offers the metal to any other customer. The company agrees to maintain the rated capacity of 5 tons per day for a period of 5 years and in case of a plant shutdown to reactivate the facility fully within 120 days.

ELECTRO METALLURGICAL CO.

The Electro Metallurgical Co. (Division of the Union Carbide & Carbon Corp.) contract (DMP-100), signed September 14, 1954, called for the construction of a \$31.5 million plant at Ashtabula, Ohio, to produce 7,500 short tons of titanium annually. The agreement stated that the company would use its own funds for the design, construction, and equipment of the facility. The company has the right to deliver to the Government whatever production it cannot sell in the commercial market, up to an annual maximum of 7,500 tons. The Govern-

ment has an option to buy 4,500 tons annually at the market price prevailing at time of delivery. The life of the agreement was to be 5 years from the time the plant began to produce titanium in commercial quantities. Initial production was to begin in 1956. The company pioneered a sodium-reduction method in place of the usual magnesium-reduction process.

ACCELERATED TAX AMORTIZATION

By Executive order, dated October 12, 1950, the President designated the chairman of the National Security Resources Board as the certifying authority for certificates of necessity for accelerated tax amortization under section 124-A of the Internal Revenue Code, as added by section 216 of the Revenue Act of 1950. Subsequently, this function was transferred to the Administrator of the Defense Production Administration, effective January 25, 1951. February 4, 1953, DPA was abolished, and the accelerated tax-amortization program was taken over by the Office of Defense Mobilization.

Certificates of necessity are separate and independent of Government loans. Applications are made separately, and a person may be granted either one or both, covering a specific project. To qualify for a certificate of necessity the project must be for a facility or service considered essential to national defense, the commodity produced must be under a current expansion goal, and the location of the facility must not be in an area that is considered a prime target for enemy attack.

If a company is granted a certificate of necessity for accelerated tax amortization, it is allowed to depreciate a certain percentage of the cost of its facilities over a 5-year period rather than the much slower tax writeoff normally allowed by the Internal Revenue Service. For example: If a company is granted a certificate of necessity to amortize 60 percent of a \$100,000 facility, it is allowed to write off \$60,000 over a period of 60 months. This has the effect of reducing the company income-tax payments during the early years of operation of the new facility. The percentage that has been allowed in the period 1950 to mid-1955 has averaged around 60 percent.

Table 68 lists the certificates of necessity that have been granted to the titanium industry. From this it may be seen that mining and beneficiating facilities have been granted a 65-percent tax amortization; primary metal facilities, a 90-percent tax amortization; melting and semifabricating facilities, a 40- to 90-percent tax amortization; and most pigment facilities, a 45-percent tax amortization.

REVOLVING STOCKPILE

A temporary revolving-stockpile program was established in August 1951 by the Federal Government to maintain capacity operation of titanium-sponge-manufacturing facilities during development of military applications and likewise to assure an increased supply of titanium and the utilization of the titanium sponge in the manner most advantageous to the national defense. Under this program the Government maintained a revolving fund of \$5 million for purchase and resale of not more than 1 million pounds of titanium sponge at a price not to exceed \$5 per pound. The revolving stockpile, in which titanium sponge was purchased for resale only, was in no way connected with the National Strategic Stockpile of essential materials. The authorization, originally intended to expire March 15, 1952, was extended to December 31, 1952, and later to December 31, 1953. By December 31, 1952, 303 tons of titanium sponge had been supplied to the revolving stockpile by E. I. du Pont de Nemours & Co., Inc., Newport, Del. Owing to the increasing military demand for titanium metal most of this material was resold to titanium fabricators, and by June 22, 1953, the stockpile was almost depleted. Therefore, because of the shortage of titanium sponge in 1953 no material was offered for Government purchase throughout the year. Titanium-sponge production in 1954 temporarily exceeded consumption, and the Government increased its "working inventory" to assure continued production; therefore, amendments were added to the revolving-fund contract, extending it to June 30, 1954, later to December 31, 1954, and still later to June 30, 1955. The latest amendment allowed the Government to purchase up to 8,000 tons of titanium sponge under the revolving-fund program. It was expected that, when the demand for titanium increased, the titanium purchased by this fund would be sold at market prices and the fund reimbursed, except for losses due to the drop in price.

This titanium was furnished to the Government by the producers in the form of sponge, which had been crushed to pass ½-inch mesh and packed in airtight steel drums. Each batch of sponge produced was crushed, thoroughly mixed, sampled, and analyzed, and a sample was melted in vacuo or under reduced pressure of argon for determination of Brinell hardness. On the basis of the results thus obtained, the batches were blended into lots, which were about 20,000 pounds each and met certain specifications for chemical composition and hardness. These lots were to be kept separate in storage so that they could be sorted and

TABLE 68.—*Certificates of necessity issued to the titanium industry or pending as of June 30, 1955*

MINING AND BENEFICIATION						
Tax amortization No.	Date filed	Date certified	Applicant	Location of facilities	Amount and percent eligible for certification	
6919	3-23-51	9-21-52	Florida Ore Processing Co.....	Melborne, Fla.....	Amount \$164,000	Percent 65
28154	6-23-54	6-9-55	Marine Minerals, Inc.....	Aiken, S. C.....	1,142,000	65
28671	11-2-54	1-21-55	Hobart Bros. Co.....	Winter Beach, Fla.....	100,000	65
TICK PRODUCTION						
2594	2-8-51	4-24-51	E. I. du Pont de Nemours & Co., Inc.	Newport, Del.....	1,331,000	90
28695	11-10-54	5-11-55	Columbia-Southern Chem. Co....	Natrum, W. Va.....	5,500,000	90
SPONGE PRODUCTION						
4107	3-12-51	5-4-51	Titanium Metals Corp. of America.	Henderson, Nev.....	14,163,000	90
11462	6-1-51	6-25-52	E. I. du Pont de Nemours & Co., Inc.	Wilmington, Del.....	11,088,000	90
24072	12-31-53	4-9-53	Cramet, Inc.....	Chattanooga, Tenn.....	25,740,000	90
27745	3-23-54	Pending	Harvey Machine Co., Inc.....	Torrance, Calif.....	24,842,000	-----
★28305	7-30-54	9-27-54	Union Carbide & Carbon Corp....	Ashtabula, Ohio.....	31,500,000	90
29016	1-21-55	3-22-55	E. I. du Pont de Nemours & Co., Inc.	Johnsonville, Tenn.....	40,000,000	90
MELTING AND SEMIFABRICATION						
2444	2-6-51	4-5-51	Rem-Cru Titanium, Inc.....	Midland, Pa.....	385,000	75
8767	4-26-51	11-6-51	do.....	do.....	124,000	65
27138	11-19-53	1-26-54	do.....	do.....	170,000	40
27379	12-29-53	5-10-54	Mallory-Sharon Titanium Corp....	Niles, Ohio.....	3,987,000	90
28112	6-14-54	8-18-54	Rem-Cru Titanium, Inc.....	Midland, Pa.....	360,000	90
28113	6-14-54	8-13-54	do.....	do.....	12,775,000	75
28694	11-10-54	1-5-55	Cramet, Inc.....	Chattanooga, Tenn.....	4,969,000	90
28878	12-28-54	Pending	Harvey Machine Co., Inc.....	Torrance, Calif.....	1,870,000	-----
29709	6-3-55	Pending	Mallory-Sharon Titanium Corp....	Weathersfield, Ohio.....	14,521,000	-----
PIGMENT PRODUCTION						
2288	2-2-51	2-29-52	American Cyanamid Co.....	Savannah, Ga.....	13,875,000	45
2334	2-2-51	3-21-52	Glidden Co.....	Baltimore, Md.....	1,907,000	45
10690	6-14-51	2-29-52	National Lead Co.....	St. Louis, Mo.....	151,000	30
24130	1-12-52	2-12-53	New Jersey Zinc Co. of Pa.....	Palmerton, Pa.....	15,000,000	45

sold for purposes for which their particular properties make them suitable.

EXPLORATION AID

The addition of rutile and brookite to Mineral Order 5 February 4, 1952, authorized the Defense Minerals Exploration Administration, United States Department of the Interior, to aid in financing the cost of projects for exploring unknown or undeveloped sources of these materials. Five applications for such assistance had been received; however, only one had been approved as of July 1, 1955.

The Defense Minerals Exploration Administration granted a contract to the National Lead Co. for exploring sand deposits in Duval County, Fla. The contract was for \$20,900; Government participation totaled 75 percent or \$15,675. The exploration was considered successful, and the project was therefore certified in January 1953. Rutile and brookite were removed from the program May 15, 1953, and restored March 23, 1954.

National Lead Co. also concluded a contract in July 1953 with the General Services Administration, under which the company agreed to

mine 2 tons of rutile ore in Hot Spring County, Ark., and experiment with this material at Government expense as a possible substitute for imported rutile.

DEPLETION ALLOWANCE

The Internal Revenue Code of 1954 included for the first time a depletion allowance for ilmenite. The code stated that, for Federal income-tax purposes, the allowance of deduction for depletion of ilmenite, rutile, and other ores containing titanium mined from deposits in the United States was 23 percent of the gross income from the property, but such allowance was not to exceed 50 percent of the net income from the property.

STRATEGIC STOCKPILING

MINERALS

Rutile was the only titanium mineral included in the National Stockpile List of Strategic and Critical Materials in 1955. As of mid-1955 no other titanium minerals had been been purchased by the Government for stockpiling. Rutile was placed in group I of the Strategic and Critical Materials List for Stockpiling in 1946. This group includes those materials acquired either by purchasing or by transfer of Government-owned surpluses. July 6, 1950, rutile was transferred to group II of the stockpiling listing, which could be acquired only through transfer of Government-owned surpluses, and was still in this group in 1955. A withdrawal of 1,000 tons of rutile from the

National Stockpile was authorized early in 1952 to partly relieve a shortage at that time.

METAL

Titanium-sponge metal was placed on the Government List of Strategic and Critical Materials July 16, 1954; however, no purchases of sponge for the stockpile had been made by mid-1955. Titanium sponge was placed in group I of the Strategic and Critical Materials List for Stockpiling.

GOVERNMENT-INDUSTRY COMMITTEES

Joint Government-industry committees were established by the Government to cope with the many problems in titanium production and fabrication. The Titanium Producers and Fabricators Industry Advisory Committee, formed under the auspices of the Business and Defense Services Administration July 17, 1952, was concerned with the basic problem of increasing titanium production for national defense. A Government Titanium Advisory Committee was organized by the Office of Defense Mobilization February 17, 1954, to facilitate coordination of Federal policies and programs with respect to the supply of titanium and to serve as a focal point for collective and disseminative technical information to industry. The Steering Group on Titanium Research and Development, formed to coordinate the work of the United States Department of Defense agencies responsible for carrying out the titanium program, is discussed in chapter 11 under the title, "Department of Defense."

APPENDIX A TO CHAPTER 13.—WORLD WAR II GOVERNMENT ORDERS

OFFICE OF PRODUCTION MANAGEMENT GENERAL IMPORTS ORDER M-63—TO CONSERVE THE SUPPLY AND DIRECT THE DISTRIBUTION OF DESIGNATED MA- TERIALS IN WHICH SHORTAGES EXIST AND WHICH ARE IMPORTED

WHEREAS: War requirements have created a shortage of the materials hereinafter set forth for defense, essential civilian and other uses; such materials are imported and due to the uncertainties of transportation in wartime the restrictions upon the disposition of such materials hereinafter set forth are necessary to prevent dispersion of such materials and to direct the distribution thereof in such manner as to satisfy war and essential civilian needs;

NOW, THEREFORE, IT IS HEREBY ORDERED THAT:

1049.1 (a) Definitions. For the purposes of this Order:

(1) "Strategic Material" means any material listed in List A.

(2) "Person" means any individual, partnership, association, business trust, corporation or any organized group of persons, whether or not incorporated.

(3) "Owner" of any material means any Person who has any property interest in such material except a Person whose interest is held solely as security for the payment of money.

(4) "Consignee" means the Person to whom a Strategic Material is consigned at the time of importation.

(5) "Import" means to transport in any manner into the Continental United States from any foreign country or from any territory or possession of the United States (including the Philippine Islands). Release from the bonded custody of the United States Bureau of Customs shall, for the purpose of this Order, be deemed a transportation.

(6) "Place of Initial Storage" means any Warehouse, Yard, Ground Storage or other place to which the Person making the entry or withdrawal from custody of the United States Bureau of Customs of Strategic Material imported after the effective date of this Order directs or has directed that such Strategic Material be transported from the port of entry to be held until disposed of pursuant to this Order.

(b) Restrictions on Importation of Strategic Materials. After the effective date of this Order, no Person, other than Metals Reserve Company and any other United

States governmental department, agency or corporation, or any agent acting for such Company, department, agency or corporation, shall, without the written authorization of the Director of Priorities, make any contract or other arrangement for the importing of any Strategic Material. This prohibition shall not prevent the importing, under the restrictions hereinafter set forth, of Strategic Material by any Person under any contract made before, or in existence on, the effective date of this order.

(c) **Restrictions on Disposition of Imported Strategic Materials.** Except as hereinafter specifically provided in paragraph (d).

(1) *Restrictions Upon Owners and Consignees:*

No Owner or Consignee of any Strategic Material which is imported after the effective date of this Order shall in any way, directly or indirectly

- (i) dispose of any interest in such Strategic Material;
- (ii) process or in any way change the physical condition of such Strategic Material;
- (iii) transfer possession, or cause or permit a transfer of possession, of such Strategic Material except to the port of entry and from the port of entry to the Place of Initial Storage of such Strategic Material; or
- (iv) change, or cause or permit a change of, the location of such Strategic Material except to the port of entry and from the port of entry to the Place of Initial Storage of such Strategic Material.

Provided: That a Consignee of Strategic Material may dispose of his interest in such Strategic Material to the extent necessary to complete any commitment or contract made prior to the effective date of this Order. The Person to whom he disposes of such interest shall be subject to all restrictions imposed upon Owners by this Order.

(2) *Restrictions Upon Banks and Persons Similarly Situated:* No bank or other Person which, as agent, pledgee, beneficiary under a trust receipt, or otherwise, has possession of or any interest in any written instrument evidencing any interest in any Strategic Material imported after the effective date of this Order shall in any way, directly or indirectly, except to the extent necessary to permit a Consignee to make a permissible disposition of Strategic Material in accordance with subparagraph (1) of this paragraph (c).

- (i) dispose of any such interest; or
- (ii) transfer possession, or cause or permit a transfer of possession, of such instrument.

(d) **Permissible Disposition of Imported Strategic Materials:**

(1) *Transfer to Governmental Agency.* Nothing contained in this Order shall prohibit any person having any interest whether as Owner, Consignee or otherwise, in any Strategic Material imported after the effective date of this Order from disposing of, or making any arrangement to dispose of, any interest in such Strategic Material to Metals Reserve Company or any other United States governmental department, agency or corporation.

(2) *Authorization by Director of Priorities.* Notwithstanding the provisions of paragraph (c), an Owner of Strategic Material imported after the effective date of this Order or a bank or other Person having possession of or an interest in a written instrument evidencing an interest in such Strategic Material, may process such Strategic Material or may dispose of any interest in such Strategic Material or any such written instrument, or transfer possession or change the location thereof, or cause or permit such a transfer of possession or change

of location, upon written authorization by the Director of Priorities. Any such person may make application in duplicate for such an authorization on Form PD-222A, attached hereto, which Form shall be addressed to Office of Production Management, Ref: M-63, Washington, D. C. (which will receive from the Collectors of Customs reports of all imports of Strategic Materials).

(3) *Exceptions.* The restrictions set forth in paragraph (c) shall not apply to any Strategic Material of which any United States governmental department, agency or corporation is the Owner at the time of importation, and shall not apply to any such Strategic Material after any United States governmental department, agency or corporation becomes the Owner thereof, and shall not apply to any Strategic Material purchased or otherwise acquired from any United States governmental department, agency or corporation.

(e) **Reports:**

(1) *Reports to Metals Reserve Company.* Promptly after the issuance of this Order, every Person other than any United States governmental department, agency or corporation, or any agent acting for any such department, agency or corporation, who has outstanding any order, contract or other arrangement for the importing of any Strategic Material or who has heretofore acquired for import any Strategic Material which has not physically arrived at the port of entry thereof when this Order becomes effective, shall report all relevant facts with respect to such Strategic Material to Metals Reserve Company, Ref: M-63, Washington, D. C. Such report shall be filed in duplicate; one copy will be transmitted to the Office of Production Management by Metals Reserve Company.

(2) *Reports to Collectors of Customs.* No Strategic Material which is imported after the effective date of this Order, other than Strategic Materials imported by or for the account of Metals Reserve Company or any other United States governmental department, agency or corporation, shall be entered for consumption or withdrawn from warehouse for consumption unless the Person making the entry or withdrawal shall file with the entry or withdrawal a statement of proposed disposition on Form PD-222B, attached hereto. Such statement shall be filed in duplicate; both copies shall be transmitted by the Collector of Customs to Metals Reserve Company, Ref: M-63, Washington, D. C., which will transmit one copy to the Office of Production Management.

(3) *Other Reports:* All persons having any interest, whether as Owner or Consignee or otherwise, in any Strategic Material imported after the effective date of this Order shall file such other reports as may be required from time to time by the Office of Production Management.

(f) *Violations.* Any Person who wilfully violates any provision of this Order or who by any act or omission falsifies records to be kept or information to be furnished pursuant to this Order may be prohibited from receiving further deliveries of any Material subject to allocation, and such further action may be taken as is deemed appropriate, including a recommendation for prosecution under Section 35 (A) of the Criminal Code (18 U. S. C. 80).

(g) **Applicability of Priorities Regulation No. 1.** This Order and all transactions affected thereby are subject to the provisions of Priorities Regulation No. 1, as amended from time to time, except to the extent that any provision hereof may be inconsistent therewith, in which case the provisions of this Order shall govern.

(h) **Effective Date.** This Order shall take effect at 12:01 a. m. of the day after the date of issuance. (P. D. Reg. 1, Aug. 27, 1941, 6 F. R. 4489; O. P. M. Reg. 3 Amended, Sept. 2, 1941, 6 F. R. 4865; E. O. 8629, Jan. 7, 1941, 6 F. R. 191; E. O. 8875, Aug. 28, 1941, 6 F. R. 4483; sec. 2 (a), Public No. 671, 76th Congress, Third Session, as amended by Public No. 89, 77th Congress, First Session; Sec. 9, Public No. 783, 76th Congress, Third Session).

Issued this 27th day of December, 1941.

J. S. KNOWLSON,
Acting Director of Priorities.

LIST A

Attached to General Imports Order M-63

The numbers listed after the following materials are commodity numbers taken from Schedule A, Statistical Classification of Imports of the Department of Commerce (issue of January 1, 1941). Materials are included in this List to the extent that they are covered by the commodity numbers listed below. Ores and concentrates bearing the materials are in all cases included.

Material	Ec. class	Commodity number
Antimony-----	1	6650. 0
	7	6651. 0
	7	6651. 1
	7	838. 180
	7	838. 210
Cadmium-----	1	674. 15
	7	676. 04
Chromium-----	1	6213. 0
Copper-----	1	6400. 4
	1	6400. 5
	7	6400. 7
	7	6400. 8
	7	6400. 9
Graphite or plumbago, crystalline flake-----	1	5930. 5
Kyanite and sillimanite-----	1	593. 95
Lead-----	1	6503. 0
	1	6504. 0
	7	6505. 1
Quicksilver or mercury-----	7	6662. 0
Rutile-----	1	6270. 2
Tungsten-----	1	6232. 0
Vanadium-----	1	6260. 0
Zinc-----	1	6557. 0
	7	6558. 2
Zirconium-----	1	6270. 5

OFFICE OF PRODUCTION MANAGEMENT GENERAL PREFERENCE ORDER M-44—TO CONSERVE THE SUPPLY AND DIRECT THE DISTRIBUTION OF TITANIUM PIG- MENTS

National Defense requirements having created extraordinary and unforeseen demands for protective and technical coatings containing titanium pigments, and civilian demand for titanium pigments having been rapidly increasing in recent years so that existing productive plants have been operating at capacity, and

The total output of the titanium pigments industry being at present insufficient to meet the total of defense needs and existing civilian demand, due to the lack of sufficient production of titanium dioxide for use as pigment, and

Due to the said excess of demand over supply, it being necessary and appropriate in the public interest and to promote national defense to allocate titanium

dioxide for use as pigment in the manner and to the extent in this Order provided:

Now therefore, it is hereby ordered,
That:

§ 1008.1 General Preference Order M-44 (a) **Applicability of Priorities Regulation No. 1.** All of the provisions and definitions of Priorities Regulation No. 1, issued by the Director of Priorities on August 27, 1941, shall be deemed a part of this Order, except in so far as they are inconsistent herewith.

(b) **Additional Definitions.** For the purposes of this Order:

(1) "Delivery" means, in addition to its regular meaning, a setting aside or earmarking.

(2) "Manufacturer" means a manufacturer using titanium pigment as one of his raw materials. Such term shall include a jobber previously handling titanium pigment for resale to manufacturers as defined in the first sentence hereof: *Provided, however*, That such jobbers shall be subject to the restrictions of paragraphs (e) and (g) hereof applicable to producers.

(3) "Month" means calendar month.

(4) "Producer" means any person producing titanium pigments.

(5) "Mandatory purchase order" means any order, the acceptance of which is compelled by any general regulation issued by the Director of Priorities, but does not include those placed under paragraph (e) (4) hereof.

(6) "Reserved quota percentage" means the percentage of each producer's production of titanium dioxide required by this Order to be set aside for the filling of mandatory purchase orders for titanium pigments and for specific allocation, as such percentage shall from time to time be prescribed by the Director of Priorities. Until further prescription such percentage shall be 20%.

(7) "Reserved titanium dioxide" means titanium dioxide set aside pursuant to this Order.

(8) "Titanium pigment" means any pigment containing commercial titanium dioxide either alone or admixed with or precipitated on inerts, extenders or opaque pigments.

(9) "Monthly average poundage" means the monthly average number of pounds of titanium dioxide content of pigments received by the manufacturer from all sources combined during the twelve months ended October 31, 1941, exclusive of mandatory purchase orders.

(10) "Basic monthly poundage" means the number of pounds of titanium dioxide content of pigments obtained by multiplying the monthly average poundage by a percentage equal to 100 minus the reserved quota percentage.

(11) "Proportionate basic monthly poundage" means the poundage of titanium dioxide content of pigments obtained by applying to the basic monthly poundage the proportion which a particular order to one producer for delivery in a specific month bears to the total of such manufacturer's orders placed with all sources of supply for delivery in the said month.

(c) **Assignment of Preference Ratings.** Every mandatory purchase order not otherwise rated is hereby assigned a rating of A-10.

(d) **Directions With Respect to Defense Orders.** (1) On and after the effective date hereof, each producer shall set aside each day an amount of titanium dioxide for manufacture into pigment to fill mandatory purchase orders and for specific allocation equal to the reserved quota percentage of such producer's total daily production of titanium dioxide. Such titanium dioxide shall, so far as is practicable, be reserved in the types usually required for mandatory purchase orders.

(2) Each producer shall accept and fill mandatory purchase orders for titanium pigment or titanium dioxide received by him from his reserved titanium dioxide in the order of their respective preference ratings, until such producer has accepted mandatory purchase orders requiring delivery in any one month of pigments of titanium dioxide content equal to the then existing reserved quota percentage of such producer's estimated monthly production of titanium dioxide. Thereafter such producer shall report such facts by telegraph to the Protective and Technical Coatings Section, Office of Production Management. The said Section by telegraph will furnish such producer with the names and addresses of all other producers who have not so exhausted their supplies of reserved titanium dioxide for the said month, and will subsequently notify such producer by telegraph of the name and address of each other producer also exhausting his supplies of reserved titanium dioxide. Each succeeding mandatory purchase order received by such producer, regardless of the preference rating applicable thereto, may be returned promptly to the person tendering the same, together with copies of the telegrams received from the Office of Production Management, showing the names and addresses of all other producers who have not exhausted their supplies of reserved titanium dioxide; subject, however, to such manufacturer's right to elect to receive the amount of titanium pigment covered by such order out of the residual supply which he would be eligible to receive, under paragraph (e) (3) hereof.

(3) Whenever, in any month, producers of titanium pigments are notified that all producers have exhausted their supplies of reserved titanium dioxide as to any particular type of pigment, each producer shall thereafter fill all mandatory purchase orders received by him and requiring delivery in that month in accordance with the regulations applicable thereto, reducing deliveries upon his nonmandatory purchase orders pro rata.

(4) All reserved titanium dioxide set aside in any one month which has not been disposed of upon mandatory purchase orders or by specific allocation prior to the end of the month succeeding such month shall thereupon be immediately available for sale to any purchaser without restriction, subject only to § 944.14 of Priorities Regulation No. 1.

(e) Directions With Respect to Residual Supply.

(1) In the event that, after providing for his reserved titanium dioxide, any producer's residual supply shall be insufficient to fill all non-mandatory purchase orders accepted by him for delivery in such month, such producer shall prorate the residual monthly supply of titanium dioxide for manufacture into pigment among non-mandatory purchase orders accompanied by the certificate prescribed by subparagraph (2) (whether contract or spot customers) in proportion to the proportionate basic monthly poundages of the manufacturers placing such orders and shall deliver, subject, however, to § 944.14 of Priorities Regulation No. 1, such pro rata shares to or upon the order of such manufacturers.

(2) Except when such delivery has been specifically authorized and directed by the Director of Priorities, no producer shall sell or deliver any titanium pigment to or for the account of any manufacturer, nor shall any manufacturer purchase or accept delivery of any such pigment, unless such producer has first received from such manufacturer a certificate covering such manufacturer's monthly requirements for the month in which delivery is to be made. Such certificate shall be in the form or forms to be prescribed by the Director of Priorities, accompanied by such duplicates or copies thereof as the Director of Priorities may prescribe. Such certificate shall,

among other things, set forth such manufacturer's proportionate basic monthly poundage with respect to such producer, together with such manufacturer's method of calculating it and shall set forth the amount of titanium pigments ordered for delivery in such month from all sources combined. No manufacturer shall order any additional amounts for delivery in such month without amending all certificates filed by him with respect to that month. The producer shall be entitled to rely upon any facts stated in any such certificate in the absence of actual knowledge to the contrary or of reason to doubt the accuracy of any of the facts stated therein.

(3) Any manufacturer who has a mandatory purchase order returned by a producer because such producer has exhausted his supply of reserved titanium dioxide and who has placed a civilian order with such producer which has been accepted in whole or in part in accordance with the provisions of this Order, shall be entitled to elect to receive the amount of titanium pigment covered by such mandatory purchase order out of the titanium pigment due him under his said civilian contract for use in filling such mandatory purchase order, in preference and priority over all non-mandatory purchase orders accepted by such producer.

(4) No producer shall refuse to accept any order from a manufacturer, who is a former customer of such producer and who meets such producer's regularly established credit terms, for delivery in such month of an amount of titanium dioxide in pigment form equal to or less than the said manufacturer's basic monthly poundage purchased from such producer.

(f) Specific Allocations. Specific allocations of reserved titanium dioxide may be made by the Director of Priorities from time to time to manufacturers caused undue hardship by the operation of this Order, or to manufacturers who are not able to certify a basic monthly poundage by reason of lack in whole or in part of a prior purchase record, and who establish that the use of titanium dioxide or titanium pigments by them is necessary and appropriate in the public interest. Such manufacturers may, in the discretion of the Director of Priorities, be assigned a basic monthly poundage for a limited period or periods of time in lieu of a specific allocation. Applications for allocations of reserved titanium dioxide, or for the assignment of a basic monthly poundage, under this paragraph shall be made in the manner and upon the form or forms prescribed by the Director of Priorities.

(g) Reports. Every producer shall, within fifteen (15) days after the end of each month, report to the Office of Production Management the amount of titanium dioxide produced by him, the amount of mandatory purchase orders filled by him in such month, the amounts of titanium dioxide in pigment form delivered on specific allocation, the amount of reserved titanium dioxide remaining on hand, and a summary tabulation of all certificates filed with such producer covering such month by manufacturers pursuant to paragraph (e) (2). Such report shall be accompanied by one complete set of the said certificates, arranged alphabetically by manufacturers.

(h) Additional Sanctions. Any manufacturer or producer who knowingly participates in an unauthorized delivery of titanium pigment, or who otherwise violates the provisions of this Order, or who makes a material misstatement in a certificate or in any other statement or report required hereunder, may, in addition to the other penalties provided therefor, be prohibited by the Director of Priorities from obtaining further deliveries of material subject to any General Preference, Allocation or Limitation Order.

(i) **Effective Date.** This Order shall take effect at the opening of business, December 1, 1941. (P. D. Reg. 1, Aug. 27, 1941, 6 F. R. 4489; O. P. M. Reg. 3 Amended, Sept. 2, 1941, 6 F. R. 4865; E. O. 8629, Jan. 7, 1941, 6 F. R. 191; E. O. 8875, Aug. 28, 1941, 6 F. R. 4483; sec. 2 (a), Public No. 671, 76th Congress, Third Session, as amended by Public No. 89, 77th Congress, First Session; sec. 9, Public No. 783, 76th Congress Third Session.)

Issued this 21st day of November 1941.

DONALD M. NELSON,
Director of Priorities.

[F. R. Doc. 41-8684; Filed, November 21, 1941; 10:49 a. m.]

WAR PRODUCTION BOARD CONSERVATION ORDER M-353 AS AMENDED DEC. 24, 1943—TITANIUM DIOXIDE

The fulfillment of requirements for the defense of the United States has created a shortage in the supply of titanium dioxide for defense, for private account and for export; and the following order is deemed necessary and appropriate in the public interest and to promote the national defense:

§ 3293.546 **Conservation Order M-353—(a) Definitions.** (1) "Titanium dioxide" means any pigment containing more than 12 percent titanium dioxide whether alone or admixed with or precipitated on inerts, extenders, or opaque pigments.

(2) "Military order" means any purchase order for titanium dioxide which is to be used in the manufacture of products delivered or to be delivered to, or to be used on, or incorporated in, material or equipment delivered or to be delivered to, the United States Army, Navy, Marine Corps, Coast Guard, Maritime Commission or the War Shipping Administration, or to or for the account of any foreign country under the Act of March 11, 1941 (Lend-Lease Act).

(b) **Inapplicability of Certain Preference Ratings.** No person shall give any effect to any preference ratings below AA-2 on any purchase order for titanium dioxide, unless the person placing such purchase order furnishes a certificate in substantially the following form signed by a duly authorized official, either manually or as provided by Priorities Regulation No. 7:

The undersigned hereby certifies to the War Production Board and to [insert name and address of supplier] that he is familiar with the provisions of Order No. M-353 and that his purchase order, dated, for titanium dioxide is a military order as defined in Order M-353.

By
(Name of purchaser)
(Signature and title of duly authorized official)

Orders rated below AA-2, not accompanied by the certificate, may be filed as unrated orders to the extent permitted by Priorities Regulation No. 1. The certificate need not be filed with the War Production Board. Any person receiving it may rely upon it in filling orders unless he knows or has reason to believe that it is false. The standard certification described in Priorities Regulation No. 7 may not be used instead.

(c) **Special Directives.** The War Production Board may at any time issue special directives to any person respecting the production or delivery of titanium, dioxide, notwithstanding the other provisions of this order.

(d) **Expiration Date of This Order.** The provisions of this order shall expire at twelve o'clock midnight, February 29, 1944, unless extended by the War Production Board.

(e) **Applicability of Regulations.** Except as provided in paragraph (b) above, this order and all transactions

affected thereby are subject to all applicable provisions of the regulations of the War Production Board, as amended from time to time.

(f) **Violations.** Any person who wilfully violates any provision of this order, or who, in connection with this order, wilfully conceals a material fact, or furnishes false information to any department or agency of the United States, is guilty of a crime, and upon conviction may be punished by fine or imprisonment. In addition, any such person may be prohibited from making or obtaining further deliveries of, or from processing or using, material under priority control and may be deprived of priorities assistance.

(g) **Communications.** All reports required to be filed hereunder and all communications concerning this order shall, unless otherwise directed, be addressed to War Production Board, Chemicals Division, Washington 25, D. C., Ref: M-353.

Issued this 24th day of December 1943.

WAR PRODUCTION BOARD,
By J. JOSEPH WHELAN,
Recording Secretary.

WAR PRODUCTION BOARD GENERAL PREFERENCE ORDER M-340 AS AMENDED MAR. 26, 1945—MISCELLANEOUS CHEMICALS

§ 3293.491 **General Preference Order M-340 (a). Definitions.** (1) "Subject chemical" means any chemical as defined in List 1 attached to this order.

(2) "Preferred order" means any purchase order for subject chemicals which are (i) ultimately to be delivered to or incorporated in material to be delivered to, the United States Army, Navy, Maritime Commission, War Shipping Administration, Panama Canal, Office of Scientific Research and Development, Veterans' Administration, or any government agency pursuant to the Act of March 11, 1941 (Lend-Lease Act), or which are (ii) ultimately to be used for any preferred purpose specified opposite the subject chemical in List 1 attached to this order. An order for a subject chemical may be certified as "preferred order" if the chemical is required to replace withdrawals from inventory within the previous 30 days to fill "preferred orders". The term "preferred order" under item (i) above shall not include any order for a military exchange or service department unless clearly identified on its face as coming within the definition of "overseas order" under Priorities Regulation 17.

(b) **Inapplicability of Certain Preference Ratings.** (1) No person shall give any effect to any preference rating below AAA on any purchase order for subject chemicals, unless the person placing the purchase order certifies that it is a "Preferred order".

(2) "Preferred orders" shall be certified in substantially the following form, duly signed by an authorized official:

Certified as Preferred Order under WPB Order M-340

(Identify purchase order if certificate is not on it or attached to it; if certificate does not cover whole order, add "as to (quantity) of (material)").

.....
(Name of purchaser)

.....
(Signature and title of duly authorized official)

The certificate may be indorsed on or attached to the purchase order and need not be filed with the War Production Board. Any person receiving the certificate may rely upon it unless he knows or has reason to believe that it is false. The standard certification of Priorities Regulation 7 may not be used instead.

(3) A person who receives a subject chemical on a certified "preferred order" shall use the chemical only for the purposes shown in paragraph (a) (2) above, unless otherwise specifically authorized in writing by the War Production Board.

(c) **Special Directions.** The War Production Board may at any time issue special directions to any person regarding production, use or delivery of subject chemicals, notwithstanding the other provisions of this order.

(d) **Applicability of Regulations.** Except as provided in paragraph (b) above, this order and all transactions affected hereby are subject to all applicable provisions of the regulations of the War Production Board, as amended from time to time.

(e) **Violations.** Any person who wilfully violates any provision of this order, or who, in connection with this order, wilfully conceals a material fact, or furnishes false information to any department or agency of the

United States, is guilty of a crime, and upon conviction may be punished by fine or imprisonment. In addition, any such person may be prohibited from making or obtaining further deliveries of, or from processing or using, material under priority control and may be deprived of priorities assistance.

(f) **Communications.** Communications concerning this order shall, unless otherwise directed, be addressed to War Production Board, Chemicals Bureau, Washington 25, D. C., Ref: M-340.

Issued this 26th day of March 1945.

WAR PRODUCTION BOARD.

LIST 1

Subject chemical	Preferred purposes under paragraph (a) (2) (ii)
1. Oxidized petrolatum, meaning high paraffinic petrolatum oxidized and processed to contain aliphatic ketones, and which is suitable for use as a base in the manufacture of rust preventative compounds or corrosion inhibitors meeting specification No. 52-C-18 such as those petrolatums known by the trade-marks Par-Al-Ketone, Alox 707, and Alox 701.	None.
2. Enamelwire naphtha, also known as E. W. naphtha, meaning a mixture of aromatic solvents derived from coke oven light oil, drip oil, or coal tar, distilling between 150 and 290° C., with at least 15 percent monomeric polymerizable constituents of the cumorene-indene type. The term does not include aromatic material for the production of E. W. naphtha, or for the production of cumorene-indene resin, or for the production of other chemicals or intermediates, or for use as solvents in the crude state.	(i) Wire and cable.
3. Precipitated calcium carbonate, meaning ultrafine particle calcium carbonate such as the chemical known as Kalvan, Witcarb R and Multifex.	(i) Wire and cable.
4. Hi-flash naphtha, meaning water white coal tar solvent naphtha, having a distillation range of 140° C. (293° F. to 200° C.) (392° F.) derived from coke oven light oils, coal tar distillates, drip oils or holder oils.	None.
5. Dipentene, meaning certain terpene solvents, consisting largely or entirely of mono cyclic terpene hydrocarbons of the empirical formula $C_{10}H_{16}$, having a distilling range and solvent power above that of turpentine.	(i) Marine paint for maintenance of ocean-going vessels; (ii) Rubber reclaiming.
6. Heat treated rosins, meaning rosin heated to a sufficiently high temperature and for a sufficient period to effect some degree of isomerization and disproportionation.	(i) Foundry cores; (ii) Wire and cable.
7. Stabilized rosins, meaning rosin stabilized by hydrogenation, dehydrogenation, or disproportionation.	(i) Manufacturing and compounding of synthetic and natural rubber; (ii) Wire and cable. (i) Wire and cable.
8. Polymerized rosins, meaning rosin which contains 20% or more of polymerized or condensed rosin acids.	(i) Foundry cores.
9. Metal resinates, meaning any rosin which has been reacted with any given metal or metallic salt and contains 1% or more of the metal combined with the rosin.	(ii) Heat setting inks.
10. Rosin, meaning gum rosin and wood rosin as defined in the Naval Stores Act of March 3, 1923.	(i) Marine paint for maintenance of ocean-going vessels; (ii) Orders rated under Order P-149 for materials for coatings for interior can linings; (iii) Ultimate use by U. S. Government Printing Office or Bureau of Printing and Engraving; (iv) Wire and cable.
11. Nitrocellulose plastics, meaning plasticized cellulose nitrate in primary unfabricated forms, such as sheets, shapes, rods, and tubes (including extruded, butt-joined, and spiral-wound tubes manufactured by the producer of the nitrocellulose plastic incorporated therein).	None.

LIST 1—Continued

[NOTE: Items 12 to 16 added March 26, 1945]

Subject chemical	Preferred purposes under paragraph (a) (2) (ii)
12. Titanium dioxide, means any pigment containing more than 12% titanium dioxide whether alone or admixed with or precipitated on inerts, extenders or opaque pigments.	(i) Marine paint for maintenance of ocean-going vessels; (ii) Orders rated under Order P-149 for materials for coatings for interior can linings; (iii) Ultimate use by U. S. Government Printing Office or Bureau of Printing and Engraving; (iv) Wire and cable.
13. Zinc sulfide, meaning any pigment containing more than 12% zinc sulfide whether alone or admixed with, or precipitated on inerts, extenders or opaque pigments. The terms include all the commercial grades of lithopone, but do not include luminescent pigments containing zinc sulfide.	(i) Marine paint for maintenance of ocean-going vessels; (ii) Orders rated under Order P-149 for materials for coatings for interior can linings; (iii) Ultimate use by U. S. Government Printing Office or Bureau of Printing and Engraving; (iv) Wire and cable.
14. Vulcanized fibre sheet and rod, meaning unfabricated or fabricated (unless attached to other items) sheet or rod formed from regular paper which has been processed through a zinc chloride bath and cured in a series of fresh water baths.	(i) Railroad track electrical insulation; (ii) Electrical insulation for electrical power transformers.
15. Paradichlorobenzene, meaning paradichlorobenzene in any form and from whatever source derived.	(i) Polydichlorostyrene; (ii) Fungicides and insecticides solely for agricultural crops (excluding all moth preventative and deodorant uses).
16. Ester gum, meaning the reaction product of wood or gum rosin and any alcohol (usually glycerin or pentaerythritol).	(i) Wire and cable.

OFFICE OF PRICE ADMINISTRATION MAXIMUM PRICE REGULATION 327—CERTAIN NONMETALLIC MINERALS

In the judgment of the Price Administrator it is necessary and proper to establish maximum prices for certain nonmetallic minerals by a specific maximum price regulation.

A statement of the considerations involved in the issuance of this regulation has been issued simultaneously herewith and filed with the Division of the Federal Register.* In the judgment of the Price Administrator the maximum prices established by this Maximum Price Regulation No. 327 are and will be generally fair and equitable and will effectuate the purposes of the Emergency Price Control Act of 1942, as amended, and Executive Order No. 9250.

Therefore, under the authority vested in the Price Administrator by the Emergency Price Control Act of 1942, as amended, and in accordance with Revised Procedural Regulation No. 1,¹ issued by the Office of Price Administration, Maximum Price Regulation No. 327, is hereby issued.

Sec.

- 1438.1 Commodities subject to this Maximum Price Regulation 327.
- 1438.2 Maximum prices for commodities listed in § 1438.1.
- 1438.3 Less than maximum prices.
- 1438.4 Packaging and transportation charges and practices.
- 1438.5 Import sales.
- 1438.6 Export sales.
- 1438.7 Idle or frozen materials.
- 1438.8 Adjustable pricing.
- 1438.9 Evasion.
- 1438.10 Records and reports.
- 1438.11 Enforcement.
- 1438.12 Applications for adjustment and petitions for amendment.
- 1438.13 Applicability of this Maximum Price Regulation 327.
- 1438.14 Effective date.

AUTHORITY: §§ 1438.1 to 1438.14, inclusive, issued pursuant to Public Laws 421 and 729, 77th Cong.; and E. O. 9250, 7 F. R. 7871.

417253 O—57—12

§ 1438.1 Commodities Subject to this Maximum Price Regulation 327. The provisions of this Maximum Price Regulation No. 327 apply to the nonmetallic minerals set forth in the following list whether in ore, concentrate, ground, meshed, expanded, or other form, quality or state. For the purposes of this Maximum Price Regulation No. 327 each form, quality or state of any such minerals shall be considered a distinct commodity.

Agate	Ilmenite
Andalusite	Industrial Diamonds
Aplite	Kaolin
Asbestos	Kieselguhr
Barite	Kyanite
Bentonite	Nepheline Syenite
Celestite	Olivine
Corundum	Pumice
Cryolite	Pumicite
Diatomaceous Earth	Quartz Pebbles
Dumortierite	Roofing Granules
Emery	Rutile
Feldspar	Sepiolite
Flint	Sillimanite
Fuller's Earth	Strontianite
Garnet	Topaz
Gilsonite	Tripoli
Graphite	Vermiculite
Greensand	Witherite
Island Spar	

§ 1438.2 Maximum Prices for Commodities Listed in § 1438.1 (a) Maximum Prices, Except as Provided in Paragraph (b) of this § 1438.2. On and after February 22, 1943, regardless of any contract, agreement, lease or other obligation, no person shall sell or deliver, and no person shall buy or receive in the course of trade or business from any seller, any of the commodities listed in § 1438.1, at a price in excess of the following maximum prices, and no person shall agree, offer, solicit, or attempt to do so.

¹ 7 F. R. 8061.

(1) The seller's maximum price shall be the highest net price charged by him for the same commodity on a delivery made during March, 1942, to a purchaser of the same class.

(2) If no such delivery was made by the seller during March, 1942, the seller's maximum price shall be his highest net offering price for the same commodity in March, 1942, to a purchaser of the same class.

(3) Whenever any seller is unable to determine his maximum price under paragraphs (a) (1) and (a) (2) of this section for any commodity covered by this regulation (each form, quality or state of each mineral being considered a distinct commodity), his maximum price shall be determined as follows:

(i) If his maximum price was determined prior to February 22, 1943, in accordance with the provisions of the General Maximum Price Regulation, that price shall be the seller's maximum price for that commodity.

(ii) In all other cases the seller shall determine the net price at which he expects to sell his commodity and shall then file such net price with the Office of Price Administration for approval as his maximum price. Such proposed selling price shall be filed with the Office of Price Administration, Second and D Streets, S. W., Washington, D. C., within fifteen days after the first sale of the commodity that is made on or after February 22, 1943.

Pending action by the Price Administrator of prices submitted for approval under this paragraph (a) (3) (ii), any such seller may sell, deliver, exchange, or offer to sell, deliver or exchange, and any person may buy, offer to buy or receive from such seller any such commodity at the price submitted for approval. If, however, the Price Administrator disapproves the price submitted, the selling price shall be revised downward to the maximum price which the Price Administrator shall approve, and any payment made in excess of the price so approved may be required to be refunded to the buyer within fifteen days after the date of the order informing the seller of such revision. In the absence of notice to the contrary from the Office of Price Administration within thirty days after a seller files such a selling price with the Office of Price Administration, the price filed shall stand approved and shall be the maximum price applicable.

When filing such a price with the office of Price Administration, the seller shall set forth, in addition to the net price, his list price, and all discounts, allowances, and differentials for all classes of buyers, a description and identification of the commodity, a statement of facts differentiating such commodity from the other commodities sold by the seller, a statement showing how the proposed price was determined, and a description of the use or uses for which the commodity is to be produced.

(b) **Maximum Prices for Certain Commodities Sold by the American Abrasive Company, Kyanite Products Corporation, the Metals Reserve Company, the Minnesota Mining & Manufacturing Company, the Pan-Chemical Company, the Western Feldspar Milling Company, and the Yancey Cyanite Co.**

(1) The American Abrasive Company, Westfield, Massachusetts, may sell and deliver, and any person may buy and receive from the American Abrasive Company, optical grades of corundum grain of sizes #60 to #250, inclusive, at prices not in excess of 9.75¢ per pound, f. o. b. the seller's mill.

(2) Kyanite Products Corporation, 11 Broadway, New York, New York, may sell and deliver, and any person may buy and receive from Kyanite Products Corporation, the following grades of Kyanite at prices not higher than those set forth below:

STANDARD KYANITE

[Net ton prices f. o. b. (Vgn. RR.) or Pamplin (N & W RR.) Va.]

	Raw	Calcined (mullite)
35 mesh:		
Less than carload lots, 100# bags	\$22.50	\$27.50
Carloads, 100# bags	21.50	26.50
Carloads in bulk	19.00	
48 or 100 mesh:		
Less than carload lots, 100# bags	24.50	29.50
Carloads, 100# bags	23.50	28.50
200 mesh:		
Less than carload lots, 100# bags	27.50	32.50
Carloads, 100# bags	26.50	31.50
325 mesh:		
Less than carload lots, 100# bags	37.50	42.50
Carloads, 100# bags	36.50	41.50

(3) The Metals Reserve Company may sell and deliver to the American Abrasive Company, Westfield, Massachusetts, and the American Abrasive Company may buy from the Metals Reserve Company, South African crystal corundum ore and South African boulder corundum ore at maximum prices of \$107 and \$74 per short ton, respectively, delivered at the purchaser's plant at Westfield, Massachusetts.

(4) The Minnesota Mining & Manufacturing Company, St. Paul, Minnesota, may sell and deliver, and any person may buy and receive from the Minnesota Mining & Manufacturing Company, green roofing granules known as No. 35, No. 350, and No. 359 at a price not higher than \$15.00 per ton.

(5) The Pan-Chemical Company, 205 First National Bank Building, Pomona, California, may sell and deliver, and any person may buy and receive from the Pan-Chemical Company, celestite having a minimum content of 90% strontium sulphate and a maximum content of 4¼% calcium sulphate at a price not in excess of \$18.67 per short ton, f. o. b. Westmorland, California.

(6) (i) The Western Feldspar Milling Company, 1333 Maple Street, Denver, Colorado, may sell and deliver, and any person may buy and receive from the Western Feldspar Milling Company, feldspar at a price not higher than that set forth below:

	F. o. b. car, Denver, Colorado, per ton
Glass grade:	
Glass makers feldspar	\$7.00
140 mesh pottery spar	8.50
140 mesh enamel spar	8.50
200 mesh pottery spar	8.50
200 mesh enamel spar	8.50
80 mesh spar sold locally	10.50

(ii) All discounts, allowances and trade practices in effect with respect to the above-listed commodity during March, 1942, by the seller shall remain in effect.

(7) The Yancey Cyanite Co., Asheville, North Carolina, may sell and deliver, and any person may buy and receive from the Yancey Cyanite Company, glass grade kyanite packed in bags at a price not in excess of \$40 a ton f. o. b. the seller's railroad shipping point.

(c) **Definitions.**

(1) When used in this Maximum Price Regulation No. 327, the term:

(i) "Net price" means the price actually charged by the seller; i. e., the list or quoted price less all discounts, allowances, and differentials.

(ii) "Offering price" means the price quoted in the seller's price list, or, if he had no such price list, the price which he regularly quoted in any other manner. But "offering price" shall not include a price intended to withhold a commodity or service from the market, or a price offered as a bargaining price by a seller who usually sells at a price lower than his asking price. "Net offering

price" means offering price less all discounts, allowances, and differentials.

(iii) "Person" includes an individual, corporation, partnership, association, or any other organized group of persons, or legal successor or representative of any of the foregoing, and includes the United States or any agency thereof, or any other government, or any of its political subdivisions, or any agency of any of the foregoing.

(iv) "Purchaser of the same class" refers to the practice adopted by the seller of setting different prices for commodities or services for sales to different purchasers or kinds of purchasers (for example, manufacturer, wholesaler, jobber, retailer, government agency, public institution, individual consumer) or for purchasers located in different areas or for different quantities or under different conditions of sale. Customary differentials in discounts on price list goods shall be among the criteria which establish differences among classes of purchasers.

(v). "Sell" includes sell, supply, dispose, barter, exchange, lease, transfer, and deliver, and contracts and offers to do any of the foregoing. The terms "sale," "selling," "sold," "seller," "buy," "purchase" and "purchaser," shall be construed accordingly.

(2) Unless the context otherwise requires, the definitions set forth in section 302 of the Emergency Price Control Act of 1942, as amended, shall apply to other terms used herein.

§ 1438.3 Less than Maximum Prices. Lower prices than those set forth in § 1438.2 may be charged, demanded, paid or offered.

§ 1438.4 Packaging and Transportation Charges and Practices. A seller may not change the packaging and transportation charges and practices which he had in effect during March, 1942, if such change would result in higher prices to his customers.

§ 1438.5 Import Sales. The maximum prices established by Revised Supplementary Regulation No. 12² to the General Maximum Price Regulation³ issued by the Office of Price Administration apply to all commodities listed in § 1438.1 imported into the forty-eight states of the United States and the District of Columbia.

§ 1438.6 Export Sales. Export sales of the commodities listed in § 1438.1 shall be subject to the provisions of Revised Maximum Export Price Regulation⁴ issued by the Office of Price Administration.

§ 1438.7 Idle or Frozen Materials. The maximum price at which any person may sell or deliver any idle or frozen commodities listed in § 1438.1 shall be determined in accordance with the provisions of Maximum Price Regulation No. 204⁵ on Idle or Frozen Materials Sold Under Priorities Regulation No. 13.

§ 1438.8 Adjustable Pricing. Any person may offer or agree to adjust or fix prices to or at prices not in excess of the maximum prices in effect at the time of delivery. In an appropriate situation, where a petition for amendment requires extended consideration, the Administrator may, upon application, grant permission to agree to adjust prices upon deliveries made during the pendency of the petition in accordance with the disposition of the petition.

§ 1438.9 Evasion. The price limitations set forth in this Maximum Price Regulation No. 327 shall not be

evaded, whether by direct or indirect methods, in connection with an offer, solicitation, agreement, sale, delivery, purchase or receipt of or relating to the commodities listed in § 1438.1, alone or in conjunction with any other commodity or by way of commission, service, transportation, or other charge, or discount, premium or other privilege, or by tying-agreement or other trade understanding, or otherwise.

§ 1438.10 Records and Reports.

(a) Every person making sales or deliveries of the commodities listed in § 1438.1, and every person making purchases or accepting delivery of the commodities listed in § 1438.1 in the course of trade or business, shall keep for inspection by the Office of Price Administration for so long a period as the Emergency Price Control Act of 1942, as amended, remains in effect complete and accurate records of each such sale, purchase, or delivery showing the date thereof, the name of the purchaser or seller, the quantity and kind of commodity sold, purchased, or delivered, and the price received or paid therefor, and each such seller shall keep a record of all discounts, differentials, and allowances which the seller had in effect during March, 1942, with a proper identification of each such discount, differential and allowance.

(b) On or before March 10, 1943, every producer shall file with the Office of Price Administration, Washington, D. C., a copy of his current price lists and discount schedules, or other statements setting forth his current selling prices for all classes of buyers, indicating in each instance his maximum price and the manner in which it was determined, unless such producer has already filed such information with that Office. The reports required under this paragraph (b) refer only to domestic transactions. Reports with respect to export prices are governed by the provisions of the Revised Maximum Export Price Regulation issued by the Office of Price Administration.

(c) Such person shall submit such other reports to the Office of Price Administration, and keep such other records in addition to or in place of the records required in paragraph (a) of this section, as the Office of Price Administration may from time to time require.

§ 1438.11 Enforcement. (a) Persons violating any provision of this Maximum Price Regulation No. 327 are subject to the criminal penalties, civil enforcement actions, and suits for treble damages provided for by the Emergency Price Control Act of 1942, as amended.

(b) Persons who have evidence of any violation of this Maximum Price Regulation No. 327, or any price schedule, regulation or order issued by the Office of Price Administration or of any acts or practices which constitute such a violation are urged to communicate with the nearest field or regional office of the Office of Price Administration or its principal office in Washington, D. C.

§ 1438.12 Applications for Adjustment and Petitions for Amendment. (a) *Application for Adjustment.*

The following adjustment provisions (subparagraphs (1) and (2)) permit the granting of relief to producers who are unable to maintain or expand their production under their existing maximum prices whenever, under (1), there is a general shortage in the essential supply of the commodity, or, under (2), the loss of the seller's production would result in higher prices to consumers. The extent of relief to be granted under each provision is set forth therein.

(1) Whenever it appears that a shortage exists or threatens to exist in the essential supply of a commodity listed in § 1438.1 and that a producer of such commodity is unable to maintain or expand his production at his maximum price or prices, the Office of Price Administration may, either on application for adjustment in accordance with the provisions of Revised Procedural Regulation No. 1

² 7 F. R. 10532; 8 F. R. 611.

³ 7 F. R. 3153, 3330, 3666, 3990, 3991, 4339, 4487, 4659, 4738, 5027, 5276, 5192, 5465, 5445, 5565, 5484, 5775, 5784, 5785, 6958, 6081, 6007, 6216, 6615, 6794, 6939, 7083, 7322, 7454, 7758, 7913, 8431, 8881, 9004, 8942, 9435, 9615, 9616, 9732, 10155, 10454. 8 F. R. 371, 1204, 1317.

⁴ 7 F. R. 3096, 3824, 4294, 4541, 5059, 7242, 8829, 9000, 10530.

⁵ 7 F. R. 6479, 7396, 8948.

or on its own motion, adjust his maximum price or prices by an amount necessary to permit the maintenance or expansion of such production upon a reasonable operating margin. In determining such margin, consideration will be given to such factors as:

(i) Revenue from sales of such commodity and from all other sources, and

(ii) Production, mining, development, milling, processing, and transportation costs, administrative and sales expenses, depreciation and depletion charges, taxes (excluding Federal and State income taxes), and capital investment.

(2) Whenever it appears that the loss of a seller's production of any commodity listed in § 1438.1 would force his customers to resort to higher priced sources of supply and that the seller is unable to maintain his production at his maximum price or prices, the Office of Price Administration may, either on application for adjustment in accordance with the provisions of Revised Procedural Regulation No. 1 or on its own motion, adjust his maximum price or prices by an amount adequate to cover his operating costs: *Provided, however*, That in no instance will the seller's maximum price be increased to a price in excess of the general level of prices prevailing for alternative sources of the supply of the commodity. The term "operating costs" shall include the cost of labor, maintenance, supplies, power taxes other than State and Federal income taxes, insurance, workmen's compensation, royalties, and other direct expenses, depreciation and depletion (wherever practicable as determined by the Bureau of Internal Revenue in the computation of the Federal income tax), and reasonable costs of selling and administration.

(3) Before filing an application for adjustment under the provisions of subparagraph (1) and (2), it is suggested that each applicant obtain from the Office of Price Administration, Washington, D. C., a statement of the specific information that will be necessary in order that his application may receive prompt action.

(b) **Petitions for Amendment.** Any person seeking amendment of any provisions of this Maximum Price Regulation No. 327 may file a petition for an amendment in accordance with the provisions of Revised Procedural Regulation No. 1, issued by the Office of Price Administration.

§ 1438.13 Applicability of This Maximum Price Regulation No. 327. The provisions of this Maximum Price Regulation No. 327 supersede the provisions of the General Maximum Price Regulation and the provisions of all other maximum price regulations with respect to sales and deliveries for which maximum prices are established by this Maximum Price Regulation No. 327.

§ 1438.14 Effective Date. This Maximum Price Regulation No. 327 (§§ 1438.1 to 1438.14, inclusive) shall become effective February 22, 1943 for the District of Columbia and the forty-eight states of the United States, and shall become effective April 12, 1943 for the territories and possessions of the United States.

Issued this 16th day of February 1943.

PRENTISS M. BROWN,
Administrator.

OFFICE OF PRICE ADMINISTRATION REVISED PRICE SCHEDULE 98—TITANIUM PIG- MENTS

This copy incorporates the following:

	Issued	Effective	Fed. Reg. citation
1355.756 as amended by Order Amending Modification Provision in Certain Revised Price Schedules.	2-5-42	3-1-42	7FR1392
Amendment No. 1.	3-10-42	3-10-42	7FR1836
1335.755 as amended by Order Amending Enforcement Sections of Certain Revised Price Schedules.	3-13-42	3-1-42	7FR2108
	3-16-42	3-16-42	7FR2132

A sharp increase in the demand for titanium pigments has occurred in recent months as a result of the national defense program. Titanium pigments are extremely important pigments, essential in the production of a great many products necessary to the armed forces and civilian population.

In December 1941, after notice had been received of a proposed price advance by one of the largest producers, the Office of Price Administration requested the five United States producers of titanium pigments not to raise prices above those quoted on October 1, 1941. This request has been complied with by all of the producers.

Speculations by others than producers have greatly increased the resale prices of titanium pigments. These speculative prices are threatening to rise to even higher levels. It is necessary to curb such speculation, not only to prevent inflationary rises in the price of titanium pigments, but also to eliminate the danger of price rises in other industries that use titanium pigments.

Accordingly, under the authority vested in me by Executive Order No. 8734, it is hereby directed that:

§ 1335.751 Maximum Prices for Titanium Pigments. On and after March 1, 1942, regardless of the terms of any contract of sale or purchase, or other commitment, no person shall sell, offer to sell, deliver or transfer titanium pigments in quantities of 50 pounds or more, and no person shall buy, offer to buy or accept delivery of titanium pigments in quantities of 50 pounds or more at prices higher than the maximum prices set forth in Appendix A, incorporated herein as § 1335.759.*

*§ 1335.751 to 1335.759, inclusive, issued under the authority contained in E.O. 8734, 8875, 6 F.R. 1917 4483.

(Executive authority superseded by Emergency Price Control Act of 1942, Pub. Law 421, 77th Cong.)

§ 1335.752 Less Than Maximum Prices. Lower prices than those set forth in § 1335.759, Appendix A, may be charged, demanded, paid or offered.*

§ 1335.753 Evasion. The price limitations set forth in Price Schedule No. 98 shall not be evaded whether by direct or indirect methods in connection with a purchase, sale, delivery or transfer of titanium pigments, alone or in conjunction with any other material or by way of any commission, service, transportation or other charge or discount, premium, or other privilege, or by tying-agreement or other trade understanding, or otherwise.*

§ 1335.754 Records and Reports. Every person making purchases or sales of titanium pigments in quantities of 50 pounds or more on or after March 1, 1942, shall keep for inspection by the Office of Price Administration for a period of not less than one year, complete and accurate records of each such purchase or sale, showing the date thereof, the name and address of the buyer and the seller, the price paid or received, and the specifications and quantity, including the size of the containers, of the titanium pigments purchased or sold.

Persons affected by Price Schedule No. 98 shall submit such reports to the Office of Price Administration as it may, from time to time, require.*

*§ 1335.755.

(a) **Enforcement.** (1) Persons violating any provision of this Revised Price Schedule No. 98 are subject to the criminal penalties, civil enforcement actions, and suits for treble damages provided for by the Emergency Price Control Act of 1942.

(2) Persons who have evidence of any violation of this Revised Price Schedule No. 98 or any price schedule regulation or order issued by the Office of Price Administration or of any acts or practices which constitute such a violation are urged to communicate with the nearest field or regional office of

the Office of Price Administration or its principal office in Washington, D. C.

§ 1335.756 Petitions for Amendment. Persons seeking any modification of this Revised Price Schedule No. 98 or an adjustment or exception not provided for therein may file petitions for amendment in accordance with the provisions of Procedural Regulation No. 1 (§§ 1300.1-1300.56)¹ issued by the Office of Price Administration.

§ 1335.757 Definitions. When used in Price Schedule No. 98 the term:

(a) "Person" means an individual, partnership, association, corporation, or other business entity;

(b) "Titanium pigments" means the grades of titanium pigments listed in § 1335.759 Appendix A hereof.

§ 1335.758 Effective Date of Price Schedule No. 98. This Schedule (§ 1335.751 to 1335.759, inclusive) shall become effective March 1, 1942.

§ 1335.758a Effective Dates of Amendment. Amendment No. 1 (1335.759(e)) to Revised Price Schedule No. 98, shall become effective March 1, 1942 and shall remain in effect until May 2, 1942.

§ 1335.759 Appendix A: Maximum Prices for Titanium Pigments. The following maximum prices are established for titanium pigments:

(a) **Deliveries in Eastern Territory**¹—

(1) *Twenty tons or more.*

Grade	Per pound delivered in bags (cents)
Titanium Dioxide (Regular Grades).....	14½
Titanium Dioxide (Chalk Resistant Grade).....	15
Titanium Dioxide (Non-Chalking Grade).....	16½
Titanium Dioxide (Rutile Regular Grade).....	15½
Titanium Dioxide (Rutile Chalk Resistant Grade).....	16
Titanium Barium Pigments.....	5¼
Titanium Calcium Pigments.....	5½
Titanium Magnesium Pigment.....	5¼
Titanium Calcium Pigment (Rutile Grade).....	5½
Lead Titanate.....	11

¹ 7 F. R. 971.

(2) *Five tons or more but less than twenty tons.* For titanium pigments sold in quantities of 5 tons or more but less than 20 tons, \$.0025 per pound may be added to the maximum prices established in subparagraph (1) of this paragraph.

(3) *One thousand pounds or more but less than five tons.* For titanium pigments sold in quantities of 1,000 or more pounds but less than 5 tons, \$.0025 per pound may be added to the maximum prices established in subparagraph (2) of this paragraph except in the case of Titanium Barium Pigment, Titanium Calcium Pigment, Titanium Magnesium Pigment, Titanium Calcium Pigment (Rutile Grade) where the maximum prices are the maximum prices established in subparagraph (2) of this paragraph.

(4) *Fifty pounds or more but less than one thousand pounds.* For titanium pigments sold in quantities of 50 pounds or more but less than 1,000 pounds, \$.0025 per pound may be added to the maximum prices established in subparagraph (3) of this paragraph except in the case of Titanium Barium Pigments, Titanium Calcium Pigments, Titanium Magnesium Pigment, and Titanium Calcium Pigment (Rutile Grade) where the maximum prices are the maximum prices established in subparagraph (2) of this paragraph and except in the case of Lead Titanate where the maximum prices are the maximum prices established in subparagraph (3) of this paragraph.

(b) **Deliveries in Western Territory.**¹ (1) *Twenty tons or more.* The maximum prices for deliveries of titanium pigments in quantities of 20 tons or more in Western Territory are the maximum prices

established in paragraph (a) of this section for deliveries in Eastern Territory, plus \$.0025 per pound.

(2) *Less than twenty tons.* The maximum prices for deliveries of titanium pigments in quantities of less than 20 tons in Western Territory are the maximum prices established in paragraph (a) above for deliveries in Eastern Territory, plus \$.0025 per pound f. o. b. warehouse in Western Territory.

(c) **Barrels.** The maximum prices for deliveries of titanium pigments in Eastern or Western Territory in barrels are the maximum prices established above in paragraph (a) or (b) of this section, whichever the case may be, plus \$.0025 per pound.

(d) **Export Sales and Sales to Persons in Territories and Possessions of the United States.** (1) *Shipments by vessel from Eastern Territory.* The maximum prices for shipment by vessel from Eastern Territory are the maximum prices established in paragraph (a) of this section f. a. s. vessel at the port of shipment plus 10% of the applicable maximum price.

(2) *Shipments by vessel from Western Territory.* The maximum prices for shipment by vessel from Western Territory are the maximum prices established in paragraph (b) of this section f. a. s. vessel at the port of shipment plus 10% of the applicable maximum price.

(3) *Overland shipments.* The maximum prices for overland shipment are the maximum prices established in paragraph (a) or (b) of this section, whichever the case may be, delivered to that station in the United States which is at or nearest to that point on the boundary at which the shipment crosses from the United States into Canada or Mexico plus 5% of the applicable maximum price except that for quantities of less than 20 tons shipped from warehouse in Western Territory the maximum prices are f. o. b. warehouse plus 5% of the applicable maximum price.

(4) **Expenses.** No expenses, commissions, or charges for service may be added to the maximum prices established by subparagraphs (1), (2) and (3) of this paragraph (d), except (i) ocean freight, (ii) marine and war risk insurance, and (iii) foreign agents' commission unless such foreign agents' commission or any part thereof is received by the exporter directly or indirectly for his own use.

(e) **American Zirconium Corporation,** a Maryland corporation with its principal office at St. Helena, Baltimore, Maryland, may sell, deliver or transfer the various grades of titanium dioxide, referred to in § 1335.759 (a) of Revised Price Schedule No. 98 at the maximum prices established therefor in paragraphs (a), (b), (c) and (d) of § 1335.759 of Revised Price Schedule No. 98, plus 1½ cents per pound.

Issued this 5th day of February 1942.

LEON HENDERSON,
Administrator.

OFFICE OF PRICE ADMINISTRATION—STATEMENT OF CONSIDERATIONS INVOLVED IN THE ISSUANCE OF AMENDMENT 1 TO REVISED PRICE SCHEDULE 98—TITANIUM PIGMENTS

On December 31, 1941, the Price Administrator requested producers of titanium pigments not to sell those pigments at prices higher than those in effect on October 1, 1941. A large quantity of these pigments is obtained from ilmenite, an ore which was, until this country's entry into the war, principally supplied from mines in India. American Zirconium Corporation, a Maryland Corporation, with its principal office at St. Helena, Baltimore, Maryland (hereinafter sometimes referred to as the "corporation"), produces various grades of titanium dioxide, one of the pigments referred

¹ When used in this Appendix, the term "Western Territory" means the States of California, Oregon, and Washington and the term "Eastern Territory" means all other States of the United States.

to above, from ilmenite. Although there is a supply of ilmenite in this country obtained from India at a considerably lower price, the Corporation is compelled to pay \$31.50 per ton for this ore. Because of this high raw material cost, the Price Administrator, on January 24, 1942, permitted the Corporation to add 1½ cents per pound to the prices for titanium dioxide prevailing on October 1, 1941, which were established as maximum prices in his request of December 31, 1941. On February 5, 1942, the Price Administrator issued Price Schedule No. 98, establishing maximum prices for titanium pigments at the same levels which had been set by his request of December 31, 1941. This Schedule became effective March 1, 1942, the same date upon which the exception granted the Corporation from the request of December 31, 1941 expired.

Under date of February 26, 1942, the Corporation, through its President, Mr. Adrian D. Joyce, submitted a sworn statement to the Price Administrator, the substance of which is as follows: that the Corporation is compelled to pay \$31.50 per ton for ilmenite from which to produce titanium dioxide; that it is presently engaged in developing a new source of ore from its mine in Lenoir, North Carolina; that the production of ore from this mine will be available for the production of titanium dioxide on or about May 2, 1942; that ilmenite so produced can be obtained at a cost which will permit the Corporation to produce and sell titanium dioxide within the maximum price limitations established by Revised Price Schedule No. 98; that until the ore produced in said mine is available, the Corporation will be compelled to pay \$31.50 per ton for ilmenite in order to continue to produce titanium dioxide; and that the cost of such ilmenite is too high to enable the Corporation to produce and sell titanium dioxide within the maximum price limitations established by Revised Price Schedule No. 98 until the production of ilmenite from its mine in Lenoir, North Carolina is available.

The Price Administrator has determined that, from the facts as above stated, and from the facts as confirmed by an independent investigation of accountants employed by the Office of Price Administration, the Corporation has established as a fact that a temporary situation of unusual hardship exists in the operation of its business and, that, therefore American Zirconium Corporation may sell the various grades of titanium dioxide covered by Revised Price Schedule No. 98 at prices not to exceed 1½ cents per pound in excess of the maximum prices therein established, until May 2, 1942 in accordance with Amendment No. 1 to Revised Price Schedule No. 98 hereby promulgated.

Issued this 13 day of March, 1942.

JOHN E. HAMM,
Acting Price Administrator.

PART 1335—CHEMICALS

Amendment 1 to Revised Price Schedule 98—Titanium Pigments

A statement of the considerations involved in the issuance of this amendment has been prepared and is issued simultaneously herewith.²

Section 1335.759 is hereby amended by the addition of a new paragraph (e), and a new 1335.758a is added as set forth below:

1335.759 Appendix A: Maximum Prices for Titanium Pigments.

* * * * *

(e) American Zirconium Corporation, a Maryland corporation with its principal office at St. Helena,

¹ 7 F. R. 1392, 1836.

² The statement of consideration has been filed with the Division of the Federal Register.

Baltimore, Maryland, may sell, deliver or transfer the various grades of titanium dioxide, referred to in 1335.759 (a) of Revised Price Schedule No. 98 at the maximum prices established therefor in paragraphs (a), (b), (c) and (d) of 1335.759 of Revised Price Schedule No. 98, plus 1½ cents per pound. (Pub. Law 421, 77th Cong., 2d Sess.)

1335.758a Effective Dates of Amendment. Amendment No. 1 (1335.759 (e)) to Revised Price Schedule No. 98, shall become effective March 1, 1942 and shall remain in effect until May 2, 1942. (Pub. Law 421, 77th Cong. 2d Sess.)

Issued this 13th day of March 1942.

JOHN E. HAMM,
Acting Price Administrator.

(F. R. Doc. 42-2199; Filed, March 14, 1942; 9:00 a. m.)

CIVILIAN PRODUCTION ADMINISTRATION PRIORITIES REGULATION 28, SCHEDULE I, AS AMENDED DEC. 4, 1946—CRITICAL PRODUCTS

(a) **Introduction.** The table in this schedule lists certain of the critical products which the Civilian Production Administration has determined to be in such tight supply that they are serious threats to the national economy. When effective assistance of other kinds is not practicable, the CPA may assign CC preference ratings under paragraph (e) of Priorities Regulation 28 for material which is needed to sustain or increase the production of these products. In addition to the rules explained in paragraph (b) below, the general rules in paragraphs (c) and (d) of Priorities Regulation 28 governing the application for and assignment of CC ratings are also applicable. Especially important is paragraph (d) (1) of Priorities Regulation 28, requiring a determination that the use of substitute and less scarce materials is not practicable, that reasonable efforts have been made to get the required item without a rating, and that a rating is required to obtain the item by the latest date and in the minimum quantity practicable after taking into consideration material in inventory and available without a rating.

(b) Explanation of Table.

Column I—Critical products. Column I lists the critical products for which CC ratings may be granted to sustain or increase production. When "specialized machinery" for another critical product is listed in Column I, it includes only machinery and equipment designed solely for the production of that critical product. It does not include general types of equipment suitable for other use even though a particular piece of equipment is designed and built expressly for a producer of the critical product.

Column II—Persons eligible. Column II states the persons who may apply for CC ratings. Where Column VI indicates that CC ratings may be assigned for construction, the builder or contractor may apply instead of the person listed.

Column III—Production materials.

(1) If the word "yes" appears in Column III, the CPA may assign CC ratings to the person named in Column II to get production materials needed to make the item listed in Column I regardless of the applicant's minimum economic rate of operation. Where the applicant regularly sells materials as maintenance, repair or operating supplies for the item he makes, CC ratings may also be assigned to him for such supplies or for materials needed to make them. Applications for CC ratings for iron castings and steel to make items listed on Direction 18 to PR 28 should be filed as explained in that Direction. Applications for CC ratings for textile fabrics or yarns should be made under Priorities

Regulation 28A, and CC ratings may be assigned under paragraph (d) of that regulation in accordance with subparagraph (d) (5) (i).

(2) If the word "no" appears in Column III, CC ratings will be assigned for production materials only as provided in Priorities Regulation 28. The same rule applies to any production materials expressly excluded from Column III.

Column IV—Capital equipment. (1) If the word "yes" appears in Column IV, the CPA may assign CC ratings to the person named in Column II to get capital equipment which either (i) will result in a substantial increase in production of the item listed in Column I, or (ii) is needed to replace present operating equipment which is in danger of imminent breakdown.

(2) Where the word "no" appears in Column IV, CC ratings will be assigned for capital equipment only as provided in Priorities Regulation 28. The same rule applies to any capital equipment expressly excluded from Column IV.

Column V—MRO. (1) If the word "yes" appears in Column V, the CPA may assign CC ratings to the person named in Column II to get maintenance, repair and operating supplies (MRO) which he needs to use in making the item listed in Column I.

(2) If the word "no" appears in Column V, CC ratings will be assigned for MRO only as provided in Priorities Regulation 28.

Column VI—Construction. (1) If the word "yes" appears in Column VI, the CPA may assign CC ratings to the person named in Column II, or to his builder, for material needed for incorporation in new plants or in expanded or modernized old ones where increased production of the item listed in Column I will result, or where the construction is necessary to prevent a loss of production.

(2) If the word "no" appears in Column VI, CC ratings will be assigned for construction materials only as provided in Priorities Regulation 28.

I Critical products	II Person eligible	III Production materials	IV Capital equipment	V MRO	VI Construction
Alcohol (produced from non-food materials): Normal butyl alcohol	Producer	No	Yes	Yes	No
Industrial ethyl alcohol	do	No	Yes	Yes	No
Synthetic methanol	do	No	Yes	Yes	No
Asbestos-cement siding shingles and flat sheets (products made from asbestos fibres and cement).	do	No	Yes (except specialized machinery for asbestos-cement siding shingles and flat sheets).	Yes	Yes
Asbestos-cement siding shingle and flat sheet specialized machinery.	do	Yes	Yes	Yes	No
Asphalt and tarred roofing products (smooth surfaced roll roofing, mineral surfaced roll roofing, strip and individual asphalt shingles, mineral surfaced insulation board, laminated asphalt felt and mastic core type boards, saturated felts, dry roofing felts, and saturated or coated sheathing papers).	do	No	Yes (except specialized machinery for asphalt and tarred roofing products).	Yes	Yes
Asphalt and tarred roofing products specialized machinery.	do	Yes	No	Yes	No
Boilers, low pressure for residential heating.	do	Yes	Yes (replacement only).	Yes	No
Builders' hardware, of the following kinds only: (a) Butts, hinges and hasps; (b) Door locks and lock trim; (c) Sash, screen and shelf hardware; (d) Night latches and deadlocks; (e) Spring hinges; (f) Sash balances and sash pulleys.	Manufacturer	Yes	Yes (replacement only).	Yes	No
Building board (board made from wood pulp, vegetable fibres, pressed paper stock, or multiple plies of fibred stock).	Producer	No	Yes (except specialized machinery for building board).	Yes	Yes
Building board specialized machinery.	do	Yes	No	Yes	No
Castings, malleable iron and gray iron, including cast iron soil pipe, cast iron pressure pipe, and railroad car brake shoes.	Producer (foundry)	Yes	Yes	Yes	Yes
Cement, portland	Producer	Yes	Yes (replacement only) 4.	Yes	Yes (at existing plants only).
Clay building products (common and face brick, clay structural tile and clay sewer pipe).	Manufacturer	Yes	Yes (except specialized machinery for clay building products).	Yes	Yes
Clay building products specialized machinery (such as de-airing machines, extrusion heads, clay grinders and pulverizers and brick presses).	do	Yes	No	Yes	No
Coal, of the following kinds only: high grade metallurgical and by-product coking coal and double screened domestic coal in the areas comprising Bituminous Producing Districts 1, 2, 3, 4, 6, 7, 8, 9, 10, 11 and 13 (as defined in SFAW Regulation 27) and the anthracite fields of Pennsylvania.	Producer	No	Yes (except underground coal mining machinery).	Yes 1	Yes (at present mines only).
Coal mining machinery, underground.	Manufacturer	Yes	Yes	Yes	No
Concrete building products (light weight and heavy weight aggregate concrete blocks and cement brick).	do	Yes (cinders, burned clay or shale, and blast furnace slag, only).	Yes (except specialized machinery for concrete building products).	Yes	Yes
Concrete building products specialized machinery (such as concrete block and brick machines and attachments, including concrete mixers and skip loaders as commonly used in the concrete products industry).	do	Yes	No	Yes	No

footnotes at end of table.

I Critical products	II Person eligible	III Production materials	IV Capital equipment	V MRO	VI Construction
Finishing lime	Producer	No	Yes	Yes	Yes.
Furnace pipe, fittings and duct work	do	Yes	Yes (replacement only)	Yes	No.
Furnaces, warm air, including floor and wall furnaces.	do	Yes	Yes	Yes	Yes.
Gypsum board and gypsum lath	do	No	Yes (except specialized machinery for gypsum board and gypsum lath).	Yes	Yes.
Gypsum board and gypsum lath specialized machinery.	do	Yes	No	Yes	No.
Lead	Producer (mines and smelters).	Yes	Yes	Yes	Yes.
Logs	Producer (any person engaged in felling or bucking trees or transporting the yield from felled trees to the points of delivery for manufacture or shipment).	No	Yes (except special equipment produced only for use in log or sawmill operations).	Yes	Yes.
Lumber	Producer (operator of any plant, stationary or portable, which produces lumber not further manufactured than by sawing, resawing, passing lengthwise through a standard planing machine, cross-cutting to length and working, but not including any establishment known in the trade as a "distribution yard", engaged in either retail or wholesale business, even though it may process lumber on special orders from customers).	No	Yes (except special equipment produced only for use in log or sawmill operations).	Yes	Yes. ¹
Millwork, suitable for housing construction	Producer	No	Yes	Yes	Yes (at existing plants only).
Motors, electric, fractional horsepower AC	Manufacturer	Yes (except electric sheet steel).	Yes	Yes	Yes.
Penicillin	Producer	Yes	Yes	Yes	Yes.
Pipe fittings, screwed, in the following classes: (a) Gray cast recessed drainage, 2" and under; (b) Gray cast steam fittings, 3" and under (125 lbs. S. W. P.); (c) Malleable fittings including unions, 2" and under (150 lbs. S. W. P.).	Manufacturer	Yes	Yes (replacement only)	Yes	No.
Plumbing fixtures of the following types in residential-design models only (trim not included): (1) Bathtubs. (2) Kitchen sinks, including sink and tray combinations. (3) Lavatories. (4) Laundry trays. (5) Shower stalls, including receptors. (6) Water closet bowls and tanks.	Producer	Yes	Yes	Yes	Yes (at existing plants only).
Plywood, softwood	do	No	Yes	Yes	Yes (at existing plants only).
Presses, mechanical, power-driven, 150-ton and over.	do	Yes	No	Yes	No.
Pulpwood	do	No	Yes	Yes	Yes.
Radiation, convactor and cast iron	Producer	Yes	Yes	Yes	Yes.
Registers and grilles for heating systems	Manufacturer	Yes	Yes (replacement only)	Yes	No.
Rosin	Producer	Yes	Yes	Yes	Yes.
Rubber:					
GRI	do	Yes	Yes (replacement only) ¹	Yes	Yes.
GRS	do	Yes	Yes (replacement only) ¹	Yes	Yes.
Reclaimed	do	No	Yes	Yes	Yes.
Steel, electrical high silicon sheet	do	No	Yes	Yes	Yes.
Streptomycin	do	Yes	Yes	Yes	Yes.
Titanium dioxide	do	Yes	Yes	Yes	Yes.
Veneer, softwood	do	No	Yes	Yes	Yes (at existing plants only).
Wire, copper magnet	do	Yes	Yes	Yes	Yes.

See footnotes at end of table.

I Critical products	II Person eligible	III Production materials	IV Capital equipment	V MRO	VI Construction
Wiring devices (electrical) of the following kinds only: (1) Sockets, lampholders, and lamp receptacles—medium screw base types—lighting fixtures and portable lamps not included. (A lampholder consists of a socket and a housing (generally one-piece) which attaches directly to a ceiling or wall outlet, without intervening suspending or protruding devices. It may be designed so that shades and other similar appurtenances may be attached, but, in that event, the appurtenances are not part of the lampholder itself.) (2) Convenience receptacles (outlets)—types suitable for residential use. (3) Toggle switches—types designed specifically for tools and appliances not included. (4) Wall and face plates. (5) Outlet and switch (or receptacle) boxes—types suitable for residential use—including covers, hangers, supports and clamps. This only includes outlet boxes of 5-inch size or smaller, and switch (or receptacle) boxes commonly known as "gem" boxes. (6) Box connectors for residential-type metallic or nonmetallic-sheathed cable.	do	Yes (except phenolic-resin molding compound; see Schedule 121 to Order M-300).	Yes (except specialized machinery for wiring devices).	Yes	No.
Wood pulp	do	No	Yes (except specialized machinery).	Yes	Yes (expansion of existing plants only).
Woodworking machinery, including power-driven saw blades and saw bits, for the production of logs, lumber, millwork, flooring and plywood.	do	Yes	Yes	Yes	No.

¹ CC ratings will be assigned for special repair parts for underground coal mining machinery only where the repair part is essential for the continued operation of the mine and then only where it will not interfere with delivery of mining machinery for more essential purposes.

² CC ratings for construction for logs, lumber, and pulpwood will be assigned only for construction at existing plants or at plants which need to be relocated because of increased availability of timber, manpower or transportation facilities.

³ Additional equipment only for increased production of Petroleum Butadiene.

⁴ CC ratings will be assigned for capital equipment to increase production of portland cement only in areas where the CPA finds that the degree of local shortage is materially greater than the degree of national shortage.

APPENDIX B TO CHAPTER 13. 1950 TO MID-1955 GOVERNMENT ORDERS

NATIONAL PRODUCTION ADMINISTRATION REGULATION 1—INVENTORY CONTROL ¹

● Amendments are reflected in the text of the order.

Section 1. What This Regulation Does. The purpose of this regulation is to prevent the accumulation of excessive inventories of materials in short supply. It does this by limiting the quantities of such materials that can be ordered, received, or delivered.

Sec. 2. Definitions. As used in this regulation:

(a) "Person" means any individual, corporation, partnership, association, or any other organized group of persons and includes any agency of the United States or any other government.

¹ Originally issued and effective September 18, 1950, 32A CFR, Part 10, §§ 10.1—10.16, 15 F. R. 6253; reissued October 22, 1951, 32A CFR, Chapter VI, 16 F. R. 10784; as last reissued, effective December 24, 1952, 17 F. R. 11756, as subsequently amended; revoked, effective May 1, 1953.

*NPA Reg. 1, as amended December 24, 1952 (17 F. R. 11756), and as further amended by Amendment 1 of February 10, 1953 (18 F. R. 845), and by Amendment 2 of February 25, 1953 (18 F. R. 1139), is hereby revoked.

This revocation does not relieve any person of any obligation or liability incurred under NPA Reg. 1 as originally issued or as thereafter amended nor deprive any person of any rights received or accrued under said regulation prior to the effective date of this revocation. This revocation shall take effect May 1, 1953.

†The order of 10/22/51 was amended as follows: 12/14/51, 16 F. R. 12666, amended Tables IA, IB, and II; 1/28/52, 17 F. R. 866, amended Table IB; 4/2/52, 17 F. R. 2926, amended Tables IA, IB, and II; 5/16/52, 17 F. R. 4538, amended Tables IA, IB, and II; 6/30/52, 17 F. R. 5895, amended Table IB; 7/23/52, 17 F. R. 6771, amended sec. 2(b), 5(a), 5(b), 13, Tables IA, IB, and II; 9/9/52, 17 F. R. 8153, amended Tables IA, IB, and II; Amendment No. 1, effective 11/7/52, 17 F. R. 10260, amended Table IA, Chemicals, and Table II; reissued 12/24/52, 17 F. R. 11756, Tables IA, IB, and II amended; Amendment No. 1, effective 2/10/53, amended Tables IA, IB, and II, 18 F. R. 845; Amendment No. 2, effective 2/25/53, amended Table IA, IB, and II, 18 F. R. 1139.

(b) "Practicable minimum working inventory" means the smallest quantity of material from which a person can reasonably meet his deliveries or supply his services on the basis of his currently scheduled method and rate of operation. In the absence of unusual circumstances, a person's inventory will be considered more than a practicable minimum working inventory if the ratio of his inventory to his currently scheduled operations is substantially greater than the ratio which he normally maintained between his inventory and his operations during any reasonably representative period in the six months ending June 30, 1950.

Sec. 3. Materials Affected. This regulation applies only (a) to those materials listed in Table IA or Table IB (as amended from time to time) appearing at the end of this regulation, in the shapes and forms therein specified, or if no particular shape or forms of any such material is specified, then in all shapes and forms of such material, and (b) to such other materials as may be made subject to it by any other NPA regulation or order.

Sec. 4. Persons Affected. This regulation applies to all persons buying for use or resale, including resale in export trade, except an ultimate consumer with respect to the buying of materials for his personal or household use.

Sec. 5. Restrictions on Receipts. (a) Except as provided in paragraph (b) of this section, no person may receive or accept delivery of any material listed in Table IA of this regulation, if his inventory of such material is, or by reason of such receipt would become, more than a practicable minimum working inventory.

(b) No person buying for use in production or construction or for use as maintenance, repair, or operating supplies, may receive or accept delivery of any material listed in Table IB of this regulation, if his inventory of such material is, or by reason of such receipt would become, more than a practicable minimum working inventory, or more than the smallest quantity thereof reasonably required to meet his deliveries or supply his services on the basis of his currently scheduled method and rate of operation during the next succeeding number of calendar days listed for that material in column 2 of Table IB, whichever is less.

(c) In figuring his inventory a person must include all such material referred to in paragraphs (a) and (b) of this section, in his possession or held for his account by others, but not that held by him for the account of others. For the purpose of the restrictions in paragraphs (a) and (b) of this section, a material which is to be further processed is considered to be in inventory until actually put into process or actually installed or assembled. For the purpose of this regulation, processing does not include minor initial operations, such as painting, and does not include any shearing, cutting, trimming, or other operation, unless such initial operation is a part of a continuous fabricating or assembling operation; nor does it include operations such as inspection, testing, and aging, or segregation or earmarking for a specific job.

(d) Any person engaged in a seasonal business or industry who normally stocks inventory in advance of the season may, notwithstanding the restrictions in paragraphs (a) and (b) of this section, accept such advance delivery of his seasonal requirements provided that the deliveries accepted are no greater and no further in advance than those which he would normally accept in the ordinary course of his business to meet reasonably anticipated seasonal requirements.

Sec. 6. Restriction on Deliveries. No person may deliver any material if he knows, or has reason to believe, that the person requesting delivery is forbidden to receive it by this regulation.

Sec. 7. Restrictions on Ordering. (a) No person may place any order calling for delivery of any material earlier, or in larger amounts, than he would be permitted to receive under this regulation.

(b) No person may place separate orders with the same supplier, or with different suppliers, calling for delivery in the aggregate of any material in excess of the amount he is permitted to receive under this regulation even though he intends to cancel one or more of the orders before delivery.

Sec. 8. Adjustment of Orders. (a) A person who, prior to the effective date of any amendment to this regulation, has placed any order for a material calling for delivery earlier, or in greater quantities, than he is permitted to receive under this regulation must promptly cancel, reduce, or defer delivery under, every such order to the extent necessary so that delivery will not result in his exceeding his practicable minimum working inventory of such material. Nothing in this section shall affect any obligation of, or liability incurred by, a person under this regulation prior to the effective date of any amendment of this regulation.

(b) A person whose requirements change because of an alteration in his operations, slowing or stoppage of his production, or delayed delivery by suppliers, or for any other reason, must promptly cancel, reduce, or defer delivery under, his outstanding orders to the extent necessary so that delivery will not result in his exceeding his practicable minimum working inventory.

Sec. 9. Receipts Permitted After Adjustment of Orders. Where a person has promptly adjusted his outstanding orders as required by section 8 of this regulation, delivery of the material involved may be made and

accepted, and the restrictions on receipts of materials provided in this regulation may be exceeded, in any of the following cases only:

(a) If the supplier has shipped the material or loaded it for shipment before receipt of the instruction to adjust the order.

(b) If the material is a special item which, before receipt of the instruction to adjust the order, the supplier had in stock, or in production, or for the production of which he had acquired special components or special materials. For the purpose of this section a "special item" is one which the supplier does not usually make, stock, or sell, and which cannot readily be disposed of to others.

(c) If the material had already been produced or was in production before receipt of the instruction to adjust the order and cannot be used to fill other orders on the producer's books.

Sec. 10. Imported Materials. A person may import any material acquired prior to landing without regard to the inventory restrictions of this regulation. However, if his inventory of a material thereby becomes in excess of the amount permitted, he may not receive further deliveries of it from domestic sources until his inventory is reduced to permitted levels. The inventory restrictions of this regulation do apply to any deliveries of the imported material he makes, and to the amount of it that any person accepting delivery from him is permitted to receive.

Sec. 11. Minimum Production or Sales Quantities. In the case of materials that are mass produced or are normally marketed only in minimum sales quantities, a person may order and receive from a producer a minimum production run of such a material, or from any other supplier a minimum sales quantity, provided it is not practicable for him to procure his needs from other suppliers in smaller quantities, even though his inventory of such material is thereby increased beyond a practicable minimum working inventory. He may not thereafter receive additional quantities of such material until his inventory thereof is reduced below a practicable minimum working inventory.

Sec. 12. Excess Inventory. This regulation does not provide for disposal of excess inventory which may be on hand. Excess inventory may, however, be subject to requisition under certain circumstances, as provided in section 201 (a) of Title II of the Defense Production Act of 1950, as amended.

Sec. 13. Separate Operating Units. A person who has or may hereafter have more than one operating unit in his business may elect on or after July 23, 1952, to maintain separate inventory records for any of such units. After such an election has been made it may not at any time thereafter be changed without the prior written approval of NPA. The provisions of this regulation shall apply independently to any unit for which separate inventory records are maintained pursuant to this section.

Sec. 14. Relation to Other NPA Regulations and Orders. Other or additional inventory restrictions are included in certain NPA orders and other regulations presently in effect, and may be included in NPA orders and other regulations issued in the future. The inventory restrictions of any such order or other regulation shall govern to the extent that they modify this regulation. Table II at the end of this regulation includes a list of materials with respect to which quantitative inventory restrictions are provided in the orders and other regulations listed in that table, in effect on the date specified in that table. Even if an NPA order or other regulation containing inventory restrictions is not listed in Table II, a person must nevertheless comply with such restrictions. Upon revocation in any manner of the inventory restrictions

of an order or regulation listed in Table II, covering a material listed in Table IA or Table IB of this regulation, all provisions of this regulation shall apply to such material.

Sec. 15. Defense Against Claims for Damages. Persons complying with this regulation are entitled to the protection afforded by section 707 of the Defense Production Act of 1950, as amended, which provides in part that "No person shall be held liable for damages or penalties for any act or failure to act resulting directly or indirectly from his compliance with a rule, regulation, or order issued pursuant to this act, notwithstanding that any such rule, regulation, or order shall thereafter be declared by judicial or other competent authority to be invalid."

Sec. 16. Request for Adjustment or Exception. Any person affected by any provision of this regulation may file a request for adjustment or exception upon the ground that such provision works an undue or exceptional hardship upon him not suffered generally by others in the same trade or industry, or that its enforcement against him would not be in the interest of the national defense or in the public interest. In examining requests for adjustment or exception claiming that the public interest is prejudiced by the application of any provision of this regulation, consideration will be given to the requirements of the public health and safety, civilian defense, and dislocation of labor and resulting unemployment that would impair the defense program. Each request shall be in writing, by letter in triplicate, and shall set forth all pertinent facts, the nature of the relief sought, and the justification therefor.

Sec. 17. Records and Reports.

(a) Each person participating in any transaction covered by this regulation shall make and preserve, for at least 3 years thereafter, accurate and complete records of receipts, deliveries, inventories, production, and use, in sufficient detail to permit the determination, after audit, whether each transaction complies with the provisions of this regulation. This regulation does not specify any particular accounting method and does not require alteration of the system of records customarily used, provided such records supply an adequate basis for audit. Records may be retained in the form of microfilm or other photographic copies instead of the originals by those persons who, at the time such microfilm or other photographic records are made, maintain such copies of records in the regular and usual course of business.

(b) All records required by this regulation shall be made available for inspection and audit by duly authorized representatives of the National Production Authority, at the usual place of business where maintained.

(c) Persons subject to this regulation shall make such records and submit such reports to NPA as it shall require, subject to the terms of the Federal Reports Act of 1942 (5 U. S. C. 139-139F).

Sec. 18. Communications. All communications concerning this regulation shall be addressed to the National Production Authority, Washington 25, D. C., Ref: NPA Reg. 1.

Sec. 19. Violations. Any person who wilfully violates any provision of this regulation, or any other regulation or order of NPA, or who wilfully furnishes false information or conceals any material fact in the course of operation under this regulation, is guilty of a crime and upon conviction may be punished by fine or imprisonment or both. In addition, administrative action may be taken against any such person to suspend his privilege of making or receiving further deliveries of materials or using facilities under priority

or allocation control and to deprive him of further priorities assistance.

NOTE: All reporting and record-keeping requirements of this regulation have been approved by the Bureau of the Budget in accordance with the Federal Reports Act of 1942.

NPA Reg. 1, as so amended, shall take effect December 24, 1952.

TABLE 1A OF NPA REGULATION 1

(As amended December 24, 1952)

[§ 20,416]

MATERIALS SUBJECT TO PRACTICABLE WORKING INVENTORY LIMITATION

(See section 5 (a))

Building Materials

[§ 20,416.05]

Chemicals

[§ 20,416.10]

Acetylene.
Alkyl and aromatic substituted phenolic resins.
Alkyl polysulfide polymers (Thiokol-polymers, trade name).
Alpha picoline.
Argon.
Butadiene.
Calcium carbide.
Cobalt salts and driers.
Cyclohexanol.
Freon 22.
Lithium chemicals.
Lithium metal.
Nickel chemicals.
Oxygen.
Paraphenylphenol.
Paratertiary butyl phenol.
Pyrethrum.
Pyridine.
Selenium dioxide.
Toluene.

Forest Products

[§ 20,416.15]

Lumber as specified below (excluding inventories of producers or distributors, but including inventories of users).
Cedar: Port Orford.
Cypress.
Douglas fir, thick clears.
Eucalyptus: Ironbark.
Lignum vitae.
Teak.
Plywood, softwood AA grade, all thicknesses, exterior and interior; ½ inch, all grades, exterior (excluding inventories of producers or distributors but including inventories of users).

Iron and Steel

[§ 20,416.20]

Pig iron.

Steel:

Forgings (rough as forged).

Iron and steel scrap.

Non-nickel-bearing stainless (i. e., containing less than 1 percent nickel).

Metals and Minerals

[§ 20,416.25]

Aluminum scrap.
Asbestos, amosite.
Asbestos, chrysotile, spinning fibers.

Asbestos, Bolivian crocidolite.

Beryllium: Metal, oxides, master alloys, and compounds.

Chromium:

Chrome metal.

Ferro-chrome.

Cobalt: Cobalt, metal, oxides, and hydrides.

Columbium: Pure metal and chemicals, ferro-columbium, ferro-columbium-tantalum (ferro-tantalum columbium).

Copper:

Refined copper (fire-refined and electrolytic).

All copper and copper-base alloy scrap containing commercially recoverable copper.

All other copper raw materials—blister copper, copper-base alloy ingot, copper and copper-base alloy shot and waffle, brass mill castings, copper precipitates, and intermediate shapes as defined in NPA Order M-16.

Cryolite.

Diamonds, industrial.

Fluorspar, acid grade.

Magnesium:

Magnesium, primary and secondary ingots.

Semifabricated shapes.

All magnesium-base alloy scrap containing commercially recoverable magnesium.

Manganese: Manganese metal and ferro-manganese.

Mica, muscovite block and film, good stained and better.

Molybdenum:

Pure metal, powder, wire, rod, sheet.

Ferro-molybdenum, molybdenum oxide and molybdenum compounds.

Nickel:

Nickel, alloyed or unalloyed.

Imported nickel matte.

Nickel and nickel alloy, metal (cathode nickel, pigs, shot, and other primary forms).

Nickel and nickel alloy, secondary.

Nickel and nickel alloy, semifinished; bars, rods, tubes, sheet bar, ingot, blooms, billets, sheet strip, and similar mill products not further manufactured.

All nickel and nickel-base alloy scrap and nickel silver scrap containing commercially recoverable nickel.

Platinum.

Scrap, ferrous and nonferrous (except antimony, bismuth, cadmium, lead, tin, and zinc scrap).

Selenium and selenium alloys.

Tantalum:

Pure metal and chemicals.

Ferrotantalum-columbium.

Titanium:

Sponge.

Semifabricated shapes.

Sheets, tubes, extrusions.

Titanium-bearing alloys.

Titanium-base alloy scrap.

Tungsten: Pure metal, powder, wire, rod, sheet, chemical compounds, ferro-tungsten.

Vanadium: Ferro-vanadium, vanadium oxide, ammonium metal-vanadate, and other vanadium-bearing products.

Zirconium: Zirconium metal, ferro-aluminum-zirconium-silicon alloys, and all other metallic compositions used as sources of zirconium in the manufacture of any alloy products.

Textile Materials

[§ 20,416.35]

Silk, noils and waste.

Miscellaneous

[§ 20,416.40]

Bristles, pigs' and hogs'.

[§ 20,416.45]

[Containers and packaging materials, deleted by Amendment No. 1, effective 2/10/53.]

[Table IA as amended by Amendment No. 1, effective 2/10/53, 18 F. R. 845; No. 2, effective 2/25/53, 18 F. R. 1139.]

NATIONAL PRODUCTION ADMINISTRATION DSM-1—DESIGNATION OF SCARCE MATERIALS AND WITHDRAWAL OF PREVIOUS DESIGNATION¹

Section 1. Purpose of This Designation. Section 102 of the Defense Production Act of 1950, as amended, provides in part that, in order to prevent hoarding, no person shall accumulate (a) in excess of the reasonable demands of business, personal, or home consumption, or (b) for the purpose of resale at prices in excess of prevailing market prices, materials which have been designated as scarce materials or materials the supply of which would be threatened by such accumulation. This designation lists certain materials as scarce materials. It also prescribes in sections 4, 5, and 6, certain conditions under which a person may accumulate such materials in excess of the reasonable demands of business, personal, or home consumption. In addition it lists other materials which are withdrawn from their previous designation as scarce.

Sec. 2. Definition of Person. As used in this designation the word "person" includes an individual, corporation, partnership, association, or any other organized group of persons, or legal successor or representative of the foregoing, and includes the United States or any agency thereof, or any other government, or any of its political subdivisions, or any agency of any of the foregoing.

Sec. 3. Designation of Scarce Materials. Each material included in List A of this designation, in the shapes and forms therein described, or in all shapes and forms if no particular shape or form is therein described, is hereby designated, pursuant to section 102 of the Defense Production Act of 1950, as amended, a scarce material. Whenever "material" or "materials" is hereinafter used, it means any such designated material or materials.

Sec. 4. Receipts of Imported Materials. (a) Notwithstanding any provision of this designation, a person may import by land, sea, or air, any material acquired by him prior to landing without regard to the reasonable demands of his business, personal, or home consumption. However, if his total quantity of a material accumulated thereby becomes in excess of the reasonable demands of his business, personal, or home consumption, he may not receive any additional amount of such material from any domestic source until his total quantity thereof

¹ Originally issued and effective December 27, 1950, 15 F. R. 9398; redesignated as 32A C.F.R. Chapter I, Part 9, December 30, 1950, 15 F. R. 9515; amended effective January 10, 1951, 16 F. R. 319; as last amended, effective November 7, 1951, 16 F. R. 11341; redesignated as DSM 1, 16 F. R. 13132; as amended, effective June 5, 1952, 17 F. R. 5137; July 23, 1952, 17 F. R. 6771; September 9, 1952, 17 F. R. 8151; December 24, 1952, 17 F. R. 11759; February 18, 1953, 18 F. R. 981; June 18, 1953, 18 F. R. 3566.

Rubber Materials

[§ 20,416.30]

Natural rubber, dry.

has been reduced below an amount which is not in excess of the reasonable demands of his business, personal, or home consumption.

(b) Within the meaning of paragraph (a) of this section, importation by a person is not limited to the person who takes title to the material prior to landing or who pays the customs entry thereon, but includes a person who, prior to landing, purchases or contracts to purchase the material from or through an importing broker, wholesaler, or other importer, even though such broker, wholesaler, or other importer makes the customs entry in his own name, places the material on board the inland carrier for shipment to his customer, and retains title until such shipment is made. Within the meaning of paragraph (a) of this section, a material is not imported by a person who acquires such material from an importing broker, wholesaler, or other importer who took such material into his own stock or inventory.

Sec. 5. Receipts of Minimum Production or Sales Quantities. Notwithstanding any provision of this designation, in the case of materials that are mass-produced or are normally marketed only in minimum sales quantities, a person may order and receive from a producer a minimum production run of such material, or from any other supplier, a minimum sales quantity, provided it is not practicable for him to procure his needs from other suppliers in smaller quantities, even though his accumulation of such material thereby becomes in excess of the reasonable demands of his business, personal, or home consumption. After such receipt, however, he may not receive any additional amount of such material until his accumulation thereof has been reduced below an amount which is not in excess of the reasonable demands of his business, personal, or home consumption.

Sec. 6. Receipts of Materials After Adjustment of Orders. Notwithstanding any provision of this designation, a person who has promptly instructed the supplier to reduce or defer delivery of a material under an order for such material previously placed by him with the supplier, to the extent necessary so that his accumulation of such material will not be in excess of the reasonable demands of his business, personal, or home consumption, may accept delivery of the material involved in any of the following cases only:

(a) If the supplier has shipped the material or loaded it for shipment before receipt of the instruction to adjust the order.

(b) If the material is a special item which, before receipt of the instruction to adjust the order, the supplier has in stock or in production, or for the production of which he has acquired special components or special materials. For the purpose of this section a "special item" is one which the supplier does not usually make, stock, or sell, and cannot readily dispose of to others.

(c) If the material has already been produced or was in production before receipt of the instruction to adjust the order and cannot be used to fill other orders on the books of the producer.

Sec. 7. Applicability of Other Provisions of Law, Regulations, and Orders. Nothing in sections 4, 5, and 6 of this designation shall be deemed to modify in any respect, or relieve any person from complying with, any applicable regulation, order, or other provision of law.

Sec. 8. Withdrawal of Designation of Scarce Materials. The materials included in List B of this designation, as amended, all of which were designated as scarce materials in List A of NPA Designation of Scarce Materials 1 as amended February 18, 1953, are hereby withdrawn from such designation.

Designation of Scarce Materials 1, as amended, shall take effect June 18, 1953.

LIST A—DESIGNATION OF SCARCE MATERIALS

METALS AND MINERALS

Chromium—all forms of ferro-chromium including those alloys known as ferro-silicon chromium and ferro-chromium silicon, chromium nickel, chromium metal, and all other compositions containing more than 25 percent chromium, which are used as sources of chromium in commercial manufacture or processing.

Cobalt—cobalt metal, cobalt fines, cobalt oxide, cobalt powder, and all other cobalt compounds produced from ores, metals, concentrates, and/or refinery residues, as well as scrap containing more than 5 percent cobalt, which are used as sources of cobalt in commercial manufacture and processing.

Columbium and Tantalum—ferro-columbium and ferro-columbium tantalum.

Molybdenum—ferro-molybdenum, all grades of molybdenum oxide, and all primary molybdates and other molybdenum compounds used as a source of molybdenum in commercial manufacture and processing. It does not include the molybdenum present in steel scrap or pure molybdenum metal or scrap molybdenum metal.

Nickel—only the following forms of primary nickel: electrolytic nickel, ingots, pigs, rondelles, cubes, and pellets, rolled and cast anodes, shot, oxides, salts, and chemicals and residues derived directly from new nickel, including residues containing nickel derived as a byproduct from copper refinery operations.

Diamond grinding wheels.

LIST B—MATERIALS WITHDRAWN FROM THEIR PREVIOUS DESIGNATION AS SCARCE IN LIST A OF NPA DESIGNATION OF SCARCE MATERIALS 1, AS AMENDED FEBRUARY 18, 1953

CHEMICALS

Acetylene.
Alkyl and aromatic substituted phenolic resins.
Alkyl polysulfide polymers (Thiokol-polymers, trade name).
Alpha picoline.
Argon.
Butadiene.
Calcium carbide.
Cobalt salts and driers.
Cyclohexanol.
Freon 22.
Lithium chemicals.
Lithium metal.
Nickel chemicals.
Oxygen.
Paraphenylphenol.
Paratertiary butyl phenol.
Pyrethrum.
Pyridine.
Selenium compounds.
Toluene.

FOREST PRODUCTS

Lumber:
Cedar: Port Orford.
Cypress.
Douglas fir, thick clears.
Eucalyptus: Ironbark.
Lignum vitae.
Teak.
Plywood, softwood AA grade, all thicknesses, exterior and interior; ½ inch, all grades, exterior.

IRON AND STEEL

Iron: Pig iron.
Steel (carbon, including low alloy, high strength alloy, and stainless): Ingots and semifinished steel, including skelp; steel castings, rough and semifinished; structural shapes and piling; plates; rails and track

accessories; wheels and axles; bars, hot-rolled, including light shapes and reinforcing; cold-finished bars; pipe; tubing; wire, wire rods and drawn wire products; tin plate, terneplate, and tin mill black plate; hot-rolled sheet and strip; cold-rolled sheet and strip; other mill shapes and forms.

Forgings, rough as forged.

Non-nickel-bearing stainless (i. e., containing less than 1 percent nickel).

Iron and steel scrap.

METALS AND MINERALS

Aluminum:

Primary and secondary in crude form.

Semifabricated shapes, castings (including die); forgings, plate, sheet, and strip; foil; rolled structural shapes, rod, bar, and wire; extruded shapes, tube blooms, and tubing; powder, flake and paste.

All aluminum and aluminum-base scrap containing commercially recoverable aluminum.

Aluminum castings (before machining).

Aluminum forgings, pressings, and impact extrusions (before machining).

Asbestos, amosite.

Asbestos, chrysotile, spinning fibers.

Asbestos, Bolivian crocidolite.

Beryllium: Metal oxides, master alloys, and compounds.

Copper:

Refined copper (fire-refined and electrolytic) including refinery shapes such as wire, bars, slabs, cakes, billets, and ingots.

All other copper raw materials—blister copper, copper-base alloy ingot, copper and copper-base alloy shot and waffle, brass mill castings, copper precipitates, and intermediate shapes.

Copper and copper-base alloys: alloy plate, sheet, and strip; alloy rod, bar, and wire (including extruded shapes); alloy tube and pipe; unalloyed rod, bar, and wire (including extruded shapes); unalloyed plate, sheet, and strip; unalloyed tube and pipe; copper and copper-base alloy castings; copper powder mill products.

All copper and copper-base alloy scrap containing commercially recoverable copper.

Cryolite.

Diamonds, industrial.

Fluorspar, acid grade.

Magnesium:

Magnesium, primary and secondary ingots.

Semifabricated shapes.

All magnesium-base alloy scrap containing commercially recoverable magnesium.

Manganese: Manganese metal and ferro-manganese.

Mica, muscovite block and film, good stained and better.

Platinum.

Scrap, ferrous and nonferrous.

Selenium and selenium alloys.

Titanium:

Sponge.

Semifabricated shapes.

Sheets, tubes, extrusions.

Titanium-bearing alloys.

Titanium-base alloy scrap.

Tungsten: Pure metal, powder, wire, rod, sheet, chemical compounds, ferro-tungsten.

Vanadium: Ferro-vanadium, vanadium oxide, ammonium meta-vanadate and other vanadium-bearing products.

Zirconium: Zirconium metal, ferro-aluminum-zirconium-silicon alloys, and all other metallic compositions used as sources of zirconium in the manufacture of any alloy products.

RUBBER MATERIALS

Natural rubber, dry.

TEXTILE MATERIALS

Silk, noils and waste.

MISCELLANEOUS

Bristles, pigs' and hogs'.

Reels and spools, shipping and package (wholly or in part of metal).

NATIONAL PRODUCTION AUTHORITY (SALVAGE AND RECLAMATION DIVISION) LIST OF BASIC MATERIALS AND ALTERNATES—ISSUE 1

The purpose of this list is to indicate the current relative availability of the more important materials as a guide for both procurement and substitution for the Armed Services, Government Agencies and Industry. Revisions will be issued periodically to reflect any changes in availability.

"List of Basic Materials and Alternates" reviews some 550 materials grouped according to three degrees of available supply at the present time—(1) very short, (2) tight, (3) in fair supply.

Materials classifications have been determined in collaboration with: Industrial Economics Division of Policy Coordination Bureau and the various Materials Divisions of National Production Authority; Office of Materials Resources of the Munitions Board.

In making this compilation it is assumed that the Mobilization program will be continued as currently planned.

Among the important factors determining the group location for each material, are the following:

Supply	Demand
Availability of materials.	Military requirements.
Sources—domestic or foreign.	Defense-supporting programs.
Transportation required.	Stockpiles.
Production capacity.	Domestic industries.
Manpower.	Civilian economy.

GROUP SUPPLIES

The fulfillment of requirements for both defense and civilian needs already has put heavy strain on supplies of a number of key materials.

Certain alloy metals such as nickel, cobalt, and tungsten are in very short supply. All nonferrous metals are tightening rapidly.

Steel, in spite of capacity production and increased facilities is becoming critical. Only a few types and shapes are generally available.

Chemicals are spotty, with key items tending to tighten related groups, though many important categories are still in fair balance.

The range of adaptability among plastics as substitutes for metals already has resulted in such a tightening in their supply that cellulose acetate is the only important plastic still generally available.

Lumber is the one large materials group that as yet has not been affected seriously.

Released June 20, 1951.

GROUP I

Materials in Group I are in *very short supply*. Alternates should be selected for all these materials whenever possible.

GROUP II

Materials in Group II are in *tight supply*. Expanded use of these materials by industry should be avoided.

GROUP III

Materials in Group III are *in fair supply*. These materials should be used as alternates for those in Groups I and II whenever possible.

METALS

GROUP I-A-METALS

(*In very short supply*)

a—Nonferrous:

Aluminum.
Copper.
Magnesium.
Lead.
Selenium.
Tin.
Zinc.

b—Rare:

Iridium.
Osmium.
Platinum.
Rhodium.
Silver.

c—Ferrous alloys:

Cobalt.
Columbium.
Molybdenum.
Nickel.
Tantalum.
Titanium.
Tungsten.

d—Ferrous:

Bars, cold drawn.
Bars, alloy, hot rolled.
Bars and semifinished steel.
Castings, high-alloy:
Corrosive-resistant.
Heat-resistant.

Die blocks.

Forgings, heavy.

Plate, tin.

Plates.

Shapes, structural.

Sheet, galvanized.

Sheet:

Electrical.

Hot rolled.

Strip:

Cold rolled.

High carbon.

Hot rolled.

Stainless steel, nickel-bearing.

Tubing, seamless:

Carbon mechanical.

Carbon pressure.

Tubing, welded: Carbon mechanical.

Wire.

GROUP II-A-METALS

(*In tight supply*)

a—Nonferrous:

Antimony.
Bismuth.
Cadmium.
Germanium.
Tellurium.

b—Rare: None.

c—Ferrous alloys:

Chromium.
Manganese.
Silicon.
Vanadium.

d—Ferrous:

Bars, hot rolled, carbon steel.

Black sheet.

Forgings, medium.

Castings:

Iron alloy, gray.

Iron, malleable.

Steel, low alloy.

Pipe, line.

Pipe, butt weld.

Stainless steel (other).

Tubing, seamless:

Alloy mechanical.

Alloy pressure.

Tubing, welded: Carbon mechanical.

GROUP III-A-METALS

(*In fair supply*)

a—Nonferrous: None.

b—Rare: Palladium.

c—Ferrous alloys:

Boron.

Calcium.

Titanium (ferro).

Zirconium.

d—Ferrous:

Castings:

Carbon steel.

Gray iron.

Forgings, small.

Tool steel.

OFFICE OF DEFENSE MOBILIZATION DEFENSE PRODUCTION ORDER 1, SUPPLEMENT 1—SCARCE AND CRITICAL MATERIALS AUTHORIZED FOR GENERAL DISTRIBUTION IN THE CIVILIAN MARKET

Pursuant to section 101 (b) of the Defense Production Act of 1950, as amended by section 3 of the Defense Production Act Amendments of 1953, and to section 2 of Executive Order 10467 dated June 30, 1953, I have authorized the control of the general distribution in the civilian market of titanium sponge and titanium metal (ingot and mill products) and find (1) that they are scarce and critical materials essential to the national defense, and (2) that the requirements of the national defense for such materials cannot otherwise be met without creating a significant dislocation of the normal distribution of such materials in the civilian market to such a degree as to create appreciable hardship.

Titanium sponge and titanium metal (ingot and mill products) are hereby added to Schedule A of Defense Production Order 1 (18 F. R. 3805).

July 13, 1953

ARTHUR S. FLEMMING,
Director.

NATIONAL PRODUCTION AUTHORITY DELEGATION 5—DELEGATION OF AUTHORITY TO THE SECRETARY OF THE INTERIOR

Pursuant to section 902 (b) of Executive Order 10161 (Sept. 9, 1950, 15 F. R. 6105), issued under the Defense Production Act of 1950 (Pub. Law 774, 81st Cong.), there are hereby delegated to the Secretary of the Interior all functions delegated to the Secretary of Commerce by Executive Order 10161 (except to the extent that such functions may not be redelegated by the Secretary of Commerce) with respect to the following:

1. The materials listed in Column I of the attached Appendix A until processing thereof is completed by the respective facilities listed in Column II of Appendix A.

2. The manufacture and distribution of mining machinery and equipment (including private trans-

portation facilities on mining properties) the predominant use of which is in the mining industry.

The Secretary of the Interior is designated as claimant for the facilities listed in Column II of Appendix A and for the facilities involved in production of the mining machinery and equipment described above.

This delegation does not include any scrap, slag, secondary metal, manufactured oxide or refined metal except as specifically listed in Column I of Appendix A.

The authority herein delegated shall be exercised in

conformity with such production policies and programs as may be established by the National Production Authority.

The functions herein delegated may be redelegated within the Department of the Interior in the discretion of the Secretary of the Interior.

This delegation shall take effect on December 18, 1950.

CHARLES SAWYER,
Secretary of Commerce.

APPENDIX A.—ALLOCATION AND CLAIMANT RESPONSIBILITIES OF THE SECRETARY OF THE INTERIOR WITH RESPECT TO METALS AND MINERALS

COLUMN I	COLUMN II
<i>Allocating responsibilities</i>	<i>Claimant responsibilities</i>
Iron ore, concentrates, sinter, pyrites cinder.....	Mines, mills, ¹ sintering plants.
Manganese ores, concentrates.....	Mines, mills.
Chromium ores, concentrates.....	Do.
Silica, crude.....	Mines, quarries, crushing and grading plants.
Cobalt ores, concentrates.....	Mines, mills.
Nickel ores, concentrates.....	Do.
Tungsten ores, concentrates.....	Mines, mills, tungsten powder plants.
Molybdenum ores, concentrates.....	Mines, mills.
Vandium ores, concentrates, flue dust.....	Do.
Fluorspar ores.....	Do.
Miscellaneous ferro-alloy ores, concentrates (including boron, columbium, ferro-titanium, ferro-zirconium, ferro-tantalum, etc.).	Do.
Beryllium ores.....	Mines, mills, plants ² producing beryllium, chemicals, metals, or alloys.
Cerium and other rare-earth metal ores.....	Mines, dredges, mills, plants producing cerium and other rare-earth chemicals or metals.
Columbium ores.....	Mines, plants producing columbium compounds.
Germanium concentrates, residues.....	Refineries producing germanium compounds or metals.
Lithium ores.....	Mines, mills, plants producing lithium compounds or metal.
Platinum-group unrefined materials, including grain, nuggets, ores, concentrates.....	Mines, dredges, smelters, refineries.
Selenium anode slimes.....	Refineries producing selenium compounds and the element.
Tantalum ores.....	Mines, plants producing tantalum compounds or metal, consumers of ore for direct production of alloys.
Tellurium bearing anode slimes and lead residues.....	Plants producing tellurium compounds and the element.
Thallium: Cottrell dusts, residues from zinc, cadmium and lithopone works. Ores (Mercur, Utah).	Mills, plants producing compounds or metal.
Aluminum (crude), dried and calcined bauxite, alumina, aluminum pig.	Bauxite mines, drying and calcining plants alumina plants, reduction plants, secondary smelters.
Magnesium: Dolomite, magnesium chloride, magnesium pig, crystals.	Dolomite mines, electrolytic reduction plants, ferrosilicon reduction plants, melting and refining plants, secondary smelters.
Titaniferous ores, titanium metal sponge, chips, powder.	Titaniferous ore mines, reduction plants, melting plants, smelters.
Zirconium-bearing ores, zirconium metal sponge.....	Zirconium ore mines, reduction plants, melting plants, smelters.
Antimony ores, concentrates, residues.....	Mines, mills, smelters, refineries.
Arsenic concentrates, flue dusts, residues.....	Mills, primary smelters, refineries.
Bismuth concentrates, base bullion, residues.....	Mills, smelters, refineries.
Cadmium concentrates, flue dusts, residues.....	Smelters, refineries.
Copper ores, concentrates, matte, blister, anodes.....	Mines, mills, leaching plants, primary and secondary smelters, refineries, ingot makers, remelters, chemical plants.
Lead ores, concentrates, base bullion, matte, speiss, residues.	Mines, mills, primary and secondary smelters, refineries, pigment manufacturers, chemical plants.
Mercury ores, concentrates.....	Mines, mills, furnaces, retorts.
Tin ores, concentrates.....	Mines, mills, primary and secondary smelters, refineries.
Zinc ores, concentrates, fume, residues.....	Mines, mills, primary and secondary smelters, refineries, ingot makers, pigment manufacturers, chemical plants.
Diatomite, crude.....	Mines, mills.
Corundum ores, concentrates, crystals.....	Mines, crushing and grading plants.
Emery ores.....	Do.
Garnet ores, concentrates.....	Mines, mills, crushing and grading plants.
Pumice, crude.....	Mines, crushing and grading plants.
Tripoli, amorphous silica, rottenstone (crude).....	Do.

¹ "Mills," as used in this appendix, means concentrating mills or concentration plants.

² Where plants or refineries producing chemicals, pigments, compounds, metal, etc., are mentioned in column II, the reference is to plants producing such commodities from the materials specified in the opposite entry in column I.

COLUMN I

Allocating responsibilities

Grinding and sharpening stones (crude).....
 Gringing pebbles, mill liners (crude).....
 Asbestos, unmilled.....
 Calcium chloride (natural).....
 Barite, witherite (crude).....
 Borates ores, brines (crude).....
 Bromine.....
 Limestone, marl, clay, gypsum, slag.....
 Kaolin, crude.....
 Ball clay, crude.....
 Bentonite, crude.....
 Fuller's earth, crude.....
 Fire clay, crude.....
 Common clay and shale, crude.....
 Feldspar, crude.....
 Cryolite ores.....
 Gem stones, uncut.....
 Gypsum, crude.....
 Graphite, crude.....
 Greensand.....
 Magnesite.....
 Quartz, raw.....
 Sodium minerals, brines (natural).....
 Sand, gravel.....
 Slate, crude.....
 Stone, block, crushed.....
 Strontium ores.....
 Sulphur, pyrites.....
 Talc, pyrophyllite, crude.....
 Topaz, crude.....
 Vermiculite concentrates.....
 Wollastonite.....
 Kyanite and other mullite-forming minerals, synthetic mullite.....
 Mineral pigments (iron ores, etc., pyrite cinder).....
 Mica, crude, trimmed, scrap.....
 Monazite, bastnaesite.....
 Nitrogen compounds (natural).....
 Olivine, crushed.....
 Perlite, crude.....
 Roofing granules (stone, clay).....
 Salt, crude.....
 Salt brines.....
 Phosphate rock, crude.....
 Potash, crude.....

COLUMN II

Claimant responsibilities

Quarries, stone-cutting mills.
 Quarries, concentrating and cutting mills.
 Mines, mills.
 Brine processing plants.
 Barium mineral mines, beneficiating, grinding and grading plants.
 Boron mineral mines, concentrating and refining plants, brine processing plants.
 Recovery plants.
 Mines, quarries, lime plants.
 Mines, mills.
 Do.
 Do.
 Do.
 Mines.
 Clay pits.
 Mines, flotation, grinding and grading mills.
 Mines, concentrating, grinding and grading mills.
 Mines.
 Do.
 Mines, mills.
 Do.
 Mines, magnesium compound recovery plants.
 Mines, grading and cutting plants, synthesis plants.
 Brine wells, mines, refineries.
 Sand and gravel pits and plants.
 Mills.
 Quarries, mills, crushing and grading plants.
 Mines, mills.
 Native sulphur mines, mills, refineries.
 Mines, mills, block talc processing plants.
 Mills, grinding plants.
 Mines, mills, exfoliating plants.
 Mills.
 Mines, mullite synthesis plants.
 Mines, pigment plants.
 Mines, mica synthesis units, splitting or processing plants.
 Mines, processing plants.
 Mines, refineries.
 Mines.
 Mines, mills, expanding plants.
 Granule plants.
 Mines, mills, evaporated salt plants.
 Brine wells.
 Mines, mills.
 Mines, mills, brine processing plants.

DEFENSE MINERALS ADMINISTRATION

MINERAL ORDER 1—DESIGNATION OF SCARCE MATERIALS¹

Pursuant to the provisions of Section 102 of the Defense Production Act of 1950 (Public Law 774, 81st Congress), Executive Order 10161 (15 F. R. 6105), and the delegation of December 18, 1950, by the Secretary of Commerce to the Secretary of the Interior (NPA Delegation 5, 15 F. R. 9195), the materials specified on the attached list are hereby designated as scarce materials. These materials are therefore subject to said Section 102 which provides in part that in order to prevent hoarding, no person shall accumulate such materials (1) in excess of the reasonable demands of business, per-

sonal, or home consumption, or (2) for the purpose of resale at prices in excess of prevailing market prices.

Special circumstances have rendered consultation with industry representatives, including trade associations, prior to the formulation of this Order, impracticable and contrary to the interest of the national defense.

LIST OF SCARCE MATERIALS UNDER MINERAL ORDER 1

[1 28,602]

§ 1009.1 Designation of Scarce Materials.

Iron ore, concentrates, sinter, pyrites cinder
 Manganese ores, concentrates
 Chromium ores, concentrates
 Cobalt ores, concentrates
 Nickel ores, concentrates
 Tungsten ores, concentrates
 Molybdenum ores, concentrates
 Vanadium ores, concentrates, flue dust
 Fluorspar ores
 Miscellaneous ferro-alloy ores, concentrates (including boron, columbium, ferro-titanium, ferro-zirconium, ferro-tantalum, etc.)

¹ Issued by Defense Minerals Administrator, approved by Secretary of the Interior, Dec. 29, 1950, 32A CFR, Chapter VI, Part 1009, 16 F. R. 85; reassigned to 32A CFR, Chapter XII, 16 F. R. 808; revoked, effective Mar. 12, 1953, 18 F. R. 1504.*

*Mineral order 1 (16 F. R. 85) is hereby revoked.

This revocation does not relieve any person of obligation or liability incurred under Mineral Order 1 prior to the effective date thereof.

This revocation shall be effective as of the date hereof.
 Dated: Mar. 12, 1953 [18 F. R. 1504].

Beryllium ores
 Cerium and other rare-earth metal ores
 Columbium ores
 Germanium concentrates, residues
 Lithium ores
 Platinum-group unrefined materials, including grain, nuggets, ores, concentrates
 Selenium anode slimes
 Tantalum ores
 Tellurium bearing anode slimes and lead residues
 Thallium: cottrell dusts, residues from zinc, cadmium and lithopone works. Ores (Mercur, Utah)
 Aluminum (crude), dried and calcined bauxite, aluminum pig, alumina
 Magnesium: dolomite, magnesium chloride, magnesium, pig, crystals
 Titaniferous ores, titanium metal sponge, chips, powder.

DEFENSE MATERIALS PROCUREMENT ADMINISTRATION DELEGATION 5—DELEGATION OF AUTHORITY WITH RESPECT TO CERTAIN METALS AND MINERALS¹

Pursuant to Executive Orders 10161, 10200, and 10281 (15 F. R. 6105; 16 F. R. 61; 16 F. R. 8789)

¹ Originally issued by the National Production Authority as Delegation 5 to the Secretary of the Interior, effective Dec. 18, 1950, 15 F. R. 9195; amended May 5, 1951, 16 F. R. 4907; reissued, effective Jan. 29, 1952, 17 F. R. 902; amended May 16, 1952, 17 F. R. 4542; reissued, effective Dec. 2, 1952.

Defense Production Administration Delegation No. 1, as amended (16 F. R. 738; 16 F. R. 4594), and the delegation of authority in NPA Organizational Statement No. 1 (17 F. R. 4305 [¶ 20,201]), all issued under the Defense Production Act of 1950, as amended, there are hereby delegated to the Defense Materials Procurement Administrator all functions conferred upon the Secretary of Commerce by Defense Production Administration Delegation No. 1, as amended, with respect to the source materials listed in column II of the commodities listed in column I of Appendix A of this delegation.

For better general understanding of the relationship between and the respective responsibilities of the Defense Materials Procurement Agency and the National Production Authority in the field of metals and minerals, Appendix A delineates, also, the claimant responsibilities of Defense Materials Procurement Agency (column III), and the allocating and claimant responsibilities remaining with the National Production Authority (columns IV and V) for the listed commodities.

The authority herein delegated shall be exercised in conformity with such production policies and programs as may be established by the National Production Authority.

The functions herein delegated may be redelegated within the Defense Materials Procurement Agency in the discretion of the Administrator thereof.

This amended delegation shall take effect December 2, 1952.

Commodity Column I	DMPA allocating responsibility Column II	DMPA claimant responsibility Column III	NPA allocating responsibility Column IV	NPA claimant responsibility Column V
Aluminum	Crude, dried, and calcined bauxite, including refractory grades and abrasives; alumina.	Bauxite mines, drying and calcining plants; alumina plants; reduction plants.	Aluminum, pig or ingot, primary or secondary; sheet, bars, plates, and all fabricated forms; refractory products.	Foundries, rolling mills, extrusion mills, forging mills, and all other fabricating plants; secondary smelters; producers of refractories.
Magnesium	Dolomite; magnesite; magnesium chloride.	Dolomite and magnesite mining.	Magnesium ingot, primary, secondary, and alloy; sheet, and all fabricated forms; refractory products.	Reduction plants; melting and refining plants; secondary smelters; foundries, rolling mills, and all other fabricating plants; producers of refractories.
Rutile	Ores	Rutile mining and primary milling and concentrating plants.	Rutile concentrates, ground and graded.	Processing, grinding and secondary milling plants; processors of rutile concentrates.
Titanium	Titanium ores and concentrates except rutile and brookite.	Titanium ore mining, concentration and plants for the production of titanium sponge.	Ferrotitanium and alloys covered by M-80; titanium sponge and alloy ingot, primary and secondary; sheet and all fabricated forms.	Ferrotitanium plants; melting plants and secondary smelters; foundries, rolling mills and all other fabricating plants.
Zirconium	Zirconium-bearing ores	Zirconium ore mining and concentration plants.	Zirconium metal; zirconium silicon and other alloys as defined in M-80; scrap.	Reduction plants; ferroalloy plants; fabricating plants; rolling mills.
Beryllium	Ores	Mines, mills and plants, processing ore and producing beryllium chemicals, metals and alloys.	Primary and secondary beryllium metal, alloys, chemicals and compounds.	Atomic Energy Commission; instrument manufacturers; chemical and phosphor manufacturers; X-ray tube manufacturers; dielectric manufacturers.
Cerium and other rare-earth metals.	Ores	Mines, dredges, mills and chemical plants processing ore and producing rare-earth chemicals and metals.	Compounds, chemicals and metals.	Flint and alloys producers; glass and carbon arc manufacturers.
Columbium	Ores; concentrates	Mines; concentrating plants.	Columbium metal; ferrocolumbium; ferrotantalum columbium and chemicals; scrap.	Reduction plants; ferroalloy plants; rolling mills, fabricating plants; chemical producers.
Germanium .....	.....	Concentrators, smelters and refineries.	Concentrates, residues, chemicals and metal.	Fabricators and manufacturers of germanium-bearing products.
Indium .....	.....	Concentrators, smelters and refineries.	Concentrates, residues, chemicals and metal.	Fabricators and manufacturers of indium-bearing products.
Lithium	Ores	Mines, mills, plants producing lithium concentrates and metal.	Chemicals and metal	Chemical and grease manufacturers; ceramic and glass consumers; Atomic Energy Commission.
Platinum-group metals.	Unrefined materials, including grain nuggets, ores, concentrates.	Mines, dredges, mills, smelters and refineries.	Refined metals, including bars, grains, sheets, wire, solder.	Jewelers, manufacturers of electrical and chemical equipment and products, dental laboratories, manufacturers of medical equipment, pen-point makers.
Tantalum	Ores; concentrates	Mines, concentrating plants.	Tantalum metal, alloys, ferrotantalum columbium, and chemicals; scrap	Reduction plants; ferroalloy plants; chemical producers.

Commodity Column I	DMPA allocating responsibility Column II	DMPA claimant responsibility Column III	NPA allocating responsibility Column IV	NPA claimant responsibility Column V
Thallium.....	Cottrell dusts, residues from zinc, cadmium and lithopone works; ores (Mercur, Utah).	Mills, plants producing compounds or metal.	Chemicals and metal.....	Manufacturers of rodenticides, optical crystals, low-melting alloys, heavy liquids.
Chromium.....	Ores, concentrates.....	Mines, concentrating plants; sintering plants.	Chromium metal; ferro-chrome and all other chromium alloys; chromium chemicals and chromium-bearing refractories.	Reduction plants; electro-reduction plants; ferroalloy plants; chemical producers; refractory manufacturers.
Cobalt.....	Ores, concentrates.....	Mines, concentrating plants.	Cobalt metal, oxides, alloys, salts, pigments, frit and all other cobalt products.	Refineries; reduction plants; smelters; chemical producers.
Fluorspar.....	Crude ore.....	Mines, mills, excepting exclusively drying plants.	All grades of finished fluorspar including concentrates.	Producers of refractories, aluminum, steel, chemicals, glass products, ceramics and insecticides.
Iron and steel.....	Iron ore, concentrates, sinter, including sintered pyrites.	Mines, concentrating plants, sintering plants.	Pig iron; steel castings, ingots and products; scrap; chemical products.	Blast furnaces, steel foundries, plants, fabricators.

NATIONAL PRODUCTION AUTHORITY ORDER M-80—IRON AND STEEL—ALLOY- ING MATERIALS AND ALLOY PRODUCTS

This order is found necessary and appropriate to promote the national defense and is issued pursuant to authority granted by section 101 of the Defense Production Act of 1950, as amended. In the formulation of this order, there has been consultation with industry representatives, including trade association representatives, and consideration has been given to their recommendations. However, consultation with representatives of all trades and industries affected in advance of the issuance of this order has been rendered impracticable due to the necessity for immediate action and because the order affects a large number of different trades and industries.

INTRODUCTORY

- Sec.
1. What this order does.
2. Definitions.

PRODUCTION OF ALLOY PRODUCTS BY MELTING

3. Restrictions on melt.
4. Applications and reports from melters.
5. Changes in melting schedules.

PRODUCTION OF PROCESSED PRODUCTS BY MEANS OTHER THAN MELTING

6. Restrictions on processing.
7. Applications and report from processors.
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ALLOCATION OF ALLOYING MATERIALS

9. Alloying materials subject to complete allocation.
10. Restrictions on deliveries and exceptions thereto.
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PROHIBITED PRODUCTS AND USES

12. Prohibited uses of alloying materials.
13. Prohibited uses of alloy products or processed products.

GENERAL PROVISIONS

14. Schedules.
15. Conservation required.
16. Imports.
17. Relation to other NPA orders and regulations.
18. Limitation on inventories of alloying materials.
19. Export of alloying materials.
20. Applications for adjustment or exception.
21. Records and reports.
22. Communications.
23. Violations.

AUTHORITY: Sections 1 to 23 issued under sec. 704, 64 Stat. 816, as amended; 50 U. S. C. App. Sup. 2154. Interpret or apply sec. 101, 64 Stat. 799, as amended; 50 U. S. C. App. Sup. 2071, sec. 101, E. O. 10161, Sept. 9, 1950, 15 F. R. 56105; 3 CFR, 1950 Supp. sec. 2, E. O. 10200, Jan. 3, 1951, 16 F. R. 61.

INTRODUCTORY

Section 1. What This Order Does. (a) This order in general covers alloying materials and alloy products. It requires all melters and processors to file proposed melting or processing schedules and data concerning inventories. It requires authorization of melting or processing schedules by National Production Authority (hereinafter called "NPA"), and permits NPA to make changes therein. Certain schedules issued with this order require complete allocation of certain alloying materials and provide for the filing of applications with NPA for allocation authorizations; and these schedules also prohibit certain uses of specific alloying materials and alloy products. The order provides for the issuance of additional schedules when and if other alloying materials are to be made subject to allocation or to use limitations, or the use of any other alloy product is to be limited or prohibited. It contains provisions incidental to the effectuation of the foregoing in support of the Controlled Materials Plan and other programs requiring these alloying materials.

(b) Effective September 1, 1951, this order together with the schedules issued pursuant hereto and Order M-81 completely supersede present NPA Orders M-3, M-10, M-14, M-30, M-33, M-49 and M-52, and sections 14 and 18 (b) of NPA Order M-1. Order M-81 covers pure tungsten and pure molybdenum, but other forms of tungsten and molybdenum, as defined in List I of this order, are covered by this order. However, this superseder does not relieve any person of any liability or obligation incurred under any of the orders mentioned in the first sentence of this paragraph, nor does it take away any right received thereunder, it being intended that any such liabilities, obligations, and rights shall continue. Without limiting the generality of the preceding sentence, any requirements in any of the foregoing orders for filing forms or applications, or for granting any authorizations or approvals thereunder, shall continue until the date when the filing of any such forms or applications or the granting of any such authorizations or approvals is required or provided under this order and schedules; and any authorizations of melting schedules or allocations heretofore given or hereafter given pursuant to any of the foregoing orders, shall continue in full force and effect. To a certain extent, this order is a rewriting of the said existing orders for the purpose of convenience in administration and for clarity. This order contains some new provisions not contained in said orders, including among others an additional list of prohibited nickel-bearing stainless steel products.

(c) Schedules 1 to 5, inclusive, and Schedules A and B are being issued on the effective date of this order. Those schedules are as follows: Schedule 1—Nickel; Schedule 2—Cobalt; Schedule 3—Tungsten (excluding pure tungsten); Schedule 4—Molybdenum (excluding pure molybdenum); Schedule 5—Columbium and Tan-

talum; Schedule A—Nickel-Bearing Stainless Steel, High Nickel Alloy, and Nickel Silver; Schedule B—High Speed and Tool Steel.

Sec. 2. Definitions. As used in this order:

(a) "Person" means any individual, corporation, partnership, association, or any other organized group of persons, and includes any agency of the United States or any other government. A person who keeps separate inventory records for any separate operating or producing unit shall treat each such separate operating or producing unit as a separate person for the purposes of this order, unless NPA otherwise directs or permits upon application of such person.

(b) "Alloying material" means any one of the forms or compounds of the elements as listed and defined in List I appearing at the end of this order. This term does not include pure tungsten or pure molybdenum, both of which are covered by NPA Order M-81.

(c) "Restricted alloying material" means any alloying material made subject to complete allocation under the provisions of this order.

(d) "Alloy product" means and includes those kinds of steel or iron hereafter defined as "alloy steel," "stainless steel," or "tool steel," and "nonferrous wrought or cast alloys," including high temperature heat- and corrosion-resisting alloys.

(1) "Alloy steel" means any steel (other than stainless and low alloy high strength steel, as defined in subparagraphs (2) and (3) of this paragraph) which contains any one or more of the following elements in the following amounts:

Manganese in excess of 1.65 percent.
Silicon in excess of 0.60 percent.
Copper in excess of 0.60 percent.

Aluminum, boron, chromium, cobalt, columbium, molybdenum, nickel, tantalum, titanium, tungsten, vanadium, zirconium, or any other alloying element in any amount specified or known to have been added to obtain a desired alloying effect.

(2) "Stainless steel" means any steel which is heat- and corrosion-resisting steel containing 10 percent or more of chromium, either with or without nickel, molybdenum, or other elements, and containing 50 percent or more of iron. This term also includes stainless-clad steel.

(3) "Low alloy high strength steel" means only the proprietary grades of alloy steel produced and sold for this purpose.

(4) "Nonferrous wrought or cast alloys" means nickel, cobalt, copper, aluminum, and other alloys containing one or more of the elements defined in List I of this order, and with less than 50 percent iron.

(5) "Tool steel" means any steel used in the manufacture of tools for use in mechanical fixtures, precision gauges, or for hand or power hacksaws. This term includes high speed steels as defined in Schedule B of this order.

(e) "Melter" means a person who produces alloy products by melting.

(f) "Alloying material supplier" means a person who produces alloying materials.

(g) "Processed product" means a product derived wholly or partially from an alloying material, by any means or process other than melting.

(h) "Processor" means a person who produces a processed product.

All definitions contained in this section 2 or List I of this order shall be applicable to the schedules at any time issued under the provisions of this order. The word "order" as used herein may include all schedules and lists issued as parts of this order.

PRODUCTION OF ALLOY PRODUCTS BY MELTING

Sec. 3. Restrictions on Melt. No melter, who uses during any calendar month a greater quantity of any alloying material than shown on List II of this order, shall melt any such alloying material into an alloy product, except in accordance with a melting schedule which has been duly authorized by NPA under section 5 of this order: *Provided*, That, whenever an allocation authorization for the same period authorizes the use of a lesser amount of any such alloying material (which is a restricted alloying material) than permitted by the melting schedule, the use of any such restricted alloying material shall be governed by the allocation authorization rather than by the melting schedule.

Sec. 4. Applications and Reports From Melters. Each melter, who uses during any calendar month a greater quantity of any alloying material than shown in List II of this order, is hereby required to apply to NPA for approval of any proposed melting schedule on Form NPAF-60. Such application shall be filed with NPA not later than the first day of the month preceding the melt month, commencing September 1, 1951. Each melter, who uses during any calendar month a greater quantity of any alloying material than shown in List II, shall also file with NPA not later than September 7, 1951, a statement on Form NPAF-113 indicating the quantities of each alloying material in his inventory on certain dates, and shall furnish all other data required by that form. If any melter requires delivery or use of any restricted alloying material, he shall also file, simultaneously with Form NPAF-113, an application on Form NPAF-114. He shall file a separate application for each restricted alloying material required by him. Applications for allocation of restricted alloying materials are required whether or not a proposed melting schedule is approved. Authorization of a melting schedule does not carry with it authorization of an application for allocation. Whenever it is necessary in order to complete any of the above forms required to be filed under the provisions of this section any person who orders alloy products from a melter shall state in his order the end use (by classification and specific part name) for which such alloy product will be used. A melter may file an additional melting schedule or schedules for authorization at any time.

Sec. 5. Changes in Melting Schedules. NPA may make such changes, modifications, postponements, or deletions in any proposed melting schedule filed by a melter as, in the discretion of NPA, may be deemed necessary or advisable in order to bring about the maximum possible conservation of alloying materials in the interest of national defense. Modifications or changes required by NPA in the alloy content of a product shall be binding upon a melter whether the alloy content of such product is procured from alloying materials, as defined in List I of this order, and/or from scrap containing usable quantities of such alloying material. Upon completion of the review of any proposed schedule or modification thereof as provided in this section, the approval of the melting schedule as originally filed or as modified will be mailed on Form GA-35, the Melting Schedule Metallurgical Authorization, to each melter at least 10 days prior to the first day of the melt month.

PRODUCTION OF PROCESSED PRODUCTS BY MEANS OTHER THAN MELTING

Sec. 6. Restrictions on Processing. No processor, who uses during any calendar month a greater quantity of any alloying material than shown on List II of this order, shall incorporate any such alloying material into

any processed product, except in accordance with a processing schedule which has been duly authorized by NPA: *Provided*, That, whenever an allocation authorization for the same period authorizes the use of a lesser amount of any such alloying material (which is a restricted alloying material) than permitted by the processing schedule, then the use of any such restricted alloying material shall be governed by the allocation authorization rather than by the processing schedule.

Sec. 7. Applications and Reports From Processors. Each processor, who uses during any calendar month a greater quantity of any alloying material than shown in List II of this order, is required to apply to NPA for approval of any proposed processing schedule on Form NPAF-102. Such application shall be filed with NPA not later than the first day of the month preceding the processing month, commencing with September 1, 1951. Each processor who uses during any calendar month a greater quantity than shown on List II of any alloying material, shall also file with NPA on the seventh day of the month preceding the processing month, commencing September 7, 1951, a statement on Form NPAF-113 indicating the quantities of each alloying material in his inventory on certain dates, and shall furnish all other data required by that form. If any processor requires delivery or use of any restricted alloying material, he shall also file simultaneously with Form NPAF-113, an application for allocation on Form NPAF-114. He shall file a separate application for each restricted alloying material required by him. Applications for allocation of restricted alloying materials are required whether or not a proposed processing schedule is authorized. Authorization of a processing schedule does not carry with it authorization of an application for allocation. Whenever it is necessary in order to complete any of the above forms required to be filed under the provisions of this section, each person who orders processed products from a processor shall state in his purchase order the end use (by classification and specific part name) for which such processed product will be used. A processor may file an additional processing schedule or schedules for authorization at any time.

Sec. 8. Changes in Processing Schedules. NPA may make such changes, modifications, postponements, or deletions in any proposed processing schedule filed by a processor, as in the discretion of NPA may be deemed necessary or advisable in order to bring about the maximum possible conservation of alloying materials in the interests of national defense. Modifications or changes required by NPA in the alloy content of a product shall be binding upon a processor whether the alloy content of such product is procured from alloying materials, as defined in List I of this order, and/or from scrap containing usable quantities of such alloying materials. Upon completion of the review of any proposed processing schedule or modification thereof as provided in this section, the approval of the processing schedule, as originally filed or as modified, will be mailed on Form GA-41, Processing Schedule Authorization, to each processor prior to the first day of the processing month.

ALLOCATION OF ALLOYING MATERIALS

Sec. 9. Alloying Materials Subject to Complete Allocation. Schedules 1 through 5, inclusive, of this order, are being issued to continue complete allocation of nickel, cobalt, tungsten, molybdenum, and columbium and tantalum. These alloying materials are termed "restricted alloying materials." Separate schedules numbered consecutively from 6 upwards will be issued under this order for each alloying material to be made subject to complete allocation after the effective date of this order. Each numbered schedule

makes a particular alloying material subject to complete allocation and contains any special requirements, exemptions, prohibited uses, or provisions pertaining to the particular alloying material that are not contained in this order.

Sec. 10. Restrictions on Deliveries and Exceptions Thereto. (a) No alloying material supplier shall deliver to any person any restricted alloying material, except in accordance with the terms of an NPA directive, an allocation authorization issued to such alloying material supplier by NPA, or except upon receipt of the certification for users of limited quantities as required by the schedules of this order.

(b) No person shall accept delivery of a restricted alloying material from an alloying material supplier except in accordance with the terms of an allocation authorization or except upon delivery of the certificate for users of limited quantities as required by the schedules of this order.

(c) No alloying material supplier shall deliver any alloying material if he knows or has reason to believe that the person receiving the alloying material may not accept delivery thereof under this order or that he will use the alloying material in violation of this order.

(d) No person shall use in any calendar month a greater quantity of a restricted alloying material than he is authorized to use for that month by this order or by Form NPAF-114 issued by NPA. When the amount of a restricted alloying material contained in the melting schedule authorization or processing schedule authorization is not the same as the amount allocated for use on Form NPAF-114, the lesser of the authorized amounts must not be exceeded.

(e) The foregoing restrictions of this section with respect to deliveries shall not apply to deliveries of restricted alloying materials made to General Services Administration or to any other duly authorized Government agency of the United States for the purpose of stock piling.

Sec. 11. Allocation Authorizations. As set forth in sections 4 and 7 of this order, each melter and processor desiring to receive an allocation authorization for any restricted alloying material is required, commencing September 7, 1951, to file with NPA an application on Form NPAF-114. This form is required to be filed simultaneously with Form NPAF-113 on or before the seventh day of the month preceding the month in which delivery of the restricted alloying material is required. NPA may grant the application in whole or in part or may reject the application. Whenever an application is granted, in whole or in part, an authorization will be issued at least 10 days prior to the first day of the delivery month to the appropriate alloying material supplier and a copy furnished to the applicant. The copy returned to the applicant will show the amount of restricted alloying material he is authorized to use and the amount he is allowed for inventory purposes to permit continuous operation from month to month. The alloying material supplier to whom the allocation authorization is issued shall fill orders of the applicant within the limits of the allocation authorization. No person receiving any restricted alloying material may use such restricted alloying material except in accordance with an allocation authorization. An allocation authorization issued by NPA to any person shall terminate at the close of the calendar month for which such allocation authorization was granted.

PROHIBITED PRODUCTS AND USES

Sec. 12. Prohibited Uses of Alloying Materials. If the use of any alloying material for any particular purpose or product is to be prohibited, the provisions concerning such prohibition are, or will be, set forth in a schedule issued with or pursuant to this order

concerning that alloying material. No person shall use any alloying material in violation of the provisions of any schedule issued with this order or which may be issued by NPA from time to time under this order.

Sec. 13. Prohibited Uses of Alloy Products or Processed Products. On the effective date of this order, Schedule A is being issued to continue certain prohibitions with respect to the use of stainless steel, high nickel alloy steel, and nickel silver products and to add certain additional restrictions; and Schedule B is being issued to continue certain provisions and add others with respect to high speed steel and tool steel. Separate schedules lettered alphabetically may be issued under this order from time to time covering additional classes of alloy or processed products. Each schedule contains or will contain specific prohibitions or restrictions as to specific classes of alloy products or processed products and additional requirements that are not covered in this order. No person shall use or manufacture any alloy product or processed product in violation of the provisions of any schedule issued with this order or which may be issued by NPA from time to time under this order.

GENERAL PROVISIONS

Sec. 14. Schedules. Schedules issued under this order shall be numbered consecutively beginning with "1" or lettered alphabetically beginning with "A", and shall be designated according to number or letter as "Schedule _____ of NPA Order M-80." A schedule may be issued or amended without any change in the text of this order, and without any republication of this order or of any provision of this order. All provisions of any schedule shall be deemed to be incorporated into and made a part of this order as of the effective date of the schedule or amendment thereto, as the case may be. In the event of an inconsistency or conflict between the provisions of any schedule issued with this order or which may be issued by NPA from time to time under this order and the provisions of this order, the provisions of the schedule shall govern. Schedules may be issued or amended at any time and from time to time and shall remain in full force and effect until individually amended, superseded, or revoked. This order may be amended without any change in the text of any schedule issued herewith or from time to time.

Sec. 15. Conservation Required. No person shall use a restricted alloying material in the production, processing, or manufacture of an alloy or processed product when it is commercially feasible to substitute some material therefor other than a restricted alloying material. No person shall use a greater quantity or higher quality of an alloying material in the production, processing, or manufacture of any alloy or processed product than is necessary to produce, process, or manufacture any such alloy or processed product on a commercially feasible basis, unless required to meet military material specifications.

Sec. 16. Imports. Nothing contained in this order shall prohibit the importation of any restricted alloying material: *Provided*, That any such restricted alloying material after importation and delivery to or for the account of the importer shall not be further delivered, used, or consumed except in accordance with the provisions of this order.

Sec. 17. Relation to Other NPA Orders and Regulations. All provisions of any NPA regulation or order are superseded to the extent that they are inconsistent with this order or with the schedules issued herewith or from time to time, but in all other respects the provisions of such regulations and orders shall remain in full force and effect. Except as otherwise directed in writing by NPA, restricted alloying material shall

be delivered only under an allocation authorization pursuant to the provisions of this order and, accordingly, DO rated orders or other preference orders shall have no effect, except to the extent that NPA takes such DO or preference rating into account in granting an allocation authorization.

Sec. 18. Limitation on Inventories of Alloying Materials. No melter or processor, notwithstanding any allocation authorization received by him, shall place an order for any alloying material (except ferro-manganese and ferro-silicon) calling for delivery of, and no such person shall accept delivery of, any such alloying material at a time when his inventory thereof exceeds, or by acceptance of such delivery would be made to exceed, 45 calendar days' requirements at his then schedule rate and method of operation. Any melter or processor who at any time has outstanding orders for any alloying material calling for delivery earlier than, or in quantities greater than, he would be permitted to receive under this section, shall forthwith notify his supplier of the extent to which delivery cannot be accepted as scheduled, and such orders shall be adjusted accordingly. Imported as well as domestic alloying materials are subject to this order and are to be included in computing inventory: *Provided*, That any alloying material acquired prior to landing may be imported even though a person's inventory thereby becomes in excess of the amount herein permitted, but that, in such event, such person may not receive further deliveries from domestic sources until his inventory is reduced to permitted levels. Any alloying material which has been processed to any degree, but has not yet been actually incorporated into a finished or partially finished product is likewise to be included in computing inventory. The provisions of NPA Reg. 1 shall continue to apply to ferro-manganese, and, for the purposes of this order, shall also be deemed applicable to ferro-silicon.

Sec. 19. Export of Alloying Materials. Alloying materials exported from the United States, its territories or possessions, pursuant to a validated export license issued by the Office of International Trade, Department of Commerce, are exempt from all provisions of this order and of the schedules issued with this order or which may be issued by NPA from time to time under this order, except for the provisions of section 9, and paragraphs (a) and (b) of section 10 of this order, and the provisions of this order requiring the keeping of records and the making of reports.

Sec. 20. Applications for Adjustment or Exception. Any person affected by any provision of this order may file a request for adjustment or exception upon the ground that such provision works an undue or exceptional hardship upon him not suffered generally by others in the same trade or industry, or that its enforcement against him would not be in the interest of the national defense or in the public interest. In examining requests for adjustment claiming that the public interest is prejudiced by the application of any provision of this order, consideration will be given to the requirements of the public health and safety, civilian defense, and dislocation of labor and resulting unemployment that would impair the defense program. Each request shall be in writing, by letter in duplicate, shall set forth all pertinent facts and the nature of the relief sought, and shall state the justification therefor.

Sec. 21. Records and Reports. (a) Commencing September 1, 1951, every person who, at any time in a calendar month, had in his possession or under his control or who, during a calendar month consumed any restricted alloying material in greater quantities than the minimum permitted by List II of this order shall report to NPA on Form NPAF-113 on or before the seventh day of the following months. However, if he

applies on such form for an allocation of restricted alloying material for delivery during the succeeding month his application serves also as the required report.

(b) Each person participating in any transaction covered by this order shall retain in his files for at least 2 years records of receipts, deliveries, inventories, and use, in sufficient detail to permit an audit that determines for each transaction that the provisions of this order have been met. This does not specify any particular accounting method, nor does it require alteration of the system of records customarily maintained, provided the system assures an adequate basis for audit. Records may be retained in the form of microfilm or other photographic copies instead of the originals by those persons who have maintained or may maintain such microfilm or other photographic records in the regular and usual course of business.

(c) All records required by this order shall be made available at the usual place of business where maintained for inspection and audit by duly authorized representatives of NPA.

(d) Persons subject to this order shall make such records and submit such additional reports to NPA as it shall require, subject to the terms of the Federal Reports Act of 1942 (5 U. S. C. 139-139F).

Sec 22. Communications. All communications concerning this order shall be addressed to the Iron and Steel Division, National Production Authority, Washington 25, D. C., Ref: M-80.

Sec. 23. Violations. Any person who wilfully violates any provision of this order or any other order or regulation of NPA or who wilfully conceals a material fact or furnishes false information in the course of operation under this order is guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both. In addition, administrative action may be taken against any such person to suspend his privilege of making or receiving further deliveries of materials or using facilities under priority or allocation control and to deprive him of further priorities assistance.

NOTE: All reporting and record-keeping requirements of this order have been approved by the Bureau of the Budget in accordance with the Federal Reports Act of 1942.

Schedules 1 to 5, inclusive; Schedules A and B; and List I and List II are issued simultaneously with and made a part of this order.

This order shall take effect, except as otherwise provided herein, on August 15, 1951.

NATIONAL PRODUCTION
AUTHORITY,
MANLY FLEISCHMANN,
Administrator.

LIST I—DEFINITIONS OF ALLOYING MATERIALS

1. *Boron* means ferro-boron, boron metal, and all other alloys used as sources of boron.

2. *Calcium* means calcium-silicon, calcium-manganese-silicon, and metallic calcium.

3. *Chromium* means all forms of ferro-chromium including those alloys known as ferro-silicon chromium and ferro-chromium silicon, chromium nickel, chromium metal, and all other compositions containing more than 25 percent chromium, which are used as sources of chromium in commercial manufacture or processing.

4. *Cobalt* means and includes cobalt metal, cobalt oxide, cobalt fines, cobalt powder, and all other primary compounds, as well as scrap containing more than 5 percent cobalt, which are used as sources of cobalt in commercial manufacture and processing.

5. *Columbium and tantalum* mean ferro-columbium and ferro-columbium tantalum.

6. *Manganese* means ferro-manganese, manganese metal, silicomanganese, silicospiegel, spiegeleisen, and

all other compositions used as sources of manganese in the manufacture of any alloy products.

7. *Molybdenum* means ferro-molybdenum, all grades of molybdenum oxide, and all primary molybdates and other molybdenum compounds used as a source of molybdenum in commercial manufacture and processing. It does not include the molybdenum present in steel scrap or pure molybdenum metal or scrap molybdenum metal.

8. *Nickel* means only the following forms of primary nickel: electrolytic nickel, ingots, pigs, rondelles, cubes, pellets and powder, rolled and cast anodes, shot, oxides, salts, and chemicals and residues derived directly from new nickel, including residues containing nickel derived as a byproduct from copper refinery operations.

9. *Silicon* means all grades of ferro-silicon including silvery iron or silicon pig, all grades of silicon metal, and all other compositions containing more than 6 percent metallic silicon, which are used as sources of silicon in the manufacture of any alloy products.

10. *Titanium* means all grades of ferro-titanium, titanium metal, and other alloys used to add titanium in the manufacture of any alloy products.

11. *Tungsten* means ferro-tungsten, tungsten scrap, and tungsten ores and concentrates. It does not include pure tungsten metal.

(a) Tungsten scrap means steel or alloy scrap containing 1 percent or more tungsten.

(b) Tungsten ores and concentrates means any ore or concentrate, either natural or synthetic, when used as a source of tungsten in the manufacture of any alloy products.

12. *Vanadium* means all forms of ferro-vanadium, vanadium pentoxide, and all other alloys and compositions used as sources of vanadium in commercial manufacture and processing.

13. *Zirconium* means zirconium metal, ferro-aluminum-zirconium, zirconium-silicon alloys, and all other metallic compositions used as sources of zirconium in the manufacture of any alloy products.

LIST II—QUANTITIES OF CONTAINED MATERIALS IN ALLOYING MATERIALS EXEMPTED PER MONTH

1. Boron—100 pounds.
2. Calcium—1,000 pounds.
3. Chromium—2,000 pounds; except chromium metal—50 pounds.
4. Cobalt—25 pounds.
5. Columbium and tantalum—10 pounds.
6. Manganese—15 tons; except manganese metal—100 pounds.
7. Molybdenum—200 pounds.
8. Nickel—100 pounds.
9. Silicon—15 tons; except silicon metal—100 pounds.
10. Titanium—200 pounds.
11. Tungsten—25 pounds.
12. Vanadium—500 pounds.
13. Zirconium—200 pounds.

[F. R. Doc. 51-9912; Filed, Aug. 15, 1951; 5:08 p. m.]

BUSINESS AND DEFENSE SERVICES ADMINISTRATION NOTICE 1—SCARCE AND CRITICAL MATERIALS AUTHORIZED FOR GENERAL DISTRIBUTION IN THE CIVILIAN MARKET

Pursuant to section 101 (b) of the Defense Production Act of 1950 as amended by section 3 of the Defense Production Act Amendments of 1953, section 201 of Executive Order 10480 dated August 14, 1953, para-

graph 1 of Defense Mobilization Order No. 30 dated August 14, 1953, and section 3 of Department of Commerce Order 152 dated October 1, 1953, I hereby authorize the control of the general distribution in the civilian market of the materials listed in Schedule A below and find (1) that they are scarce and critical materials essential to the national defense, and (2) that the requirements of the national defense for such materials cannot otherwise be met without creating a significant dislocation of the normal distribution of such materials in the civilian market to such a degree as to create appreciable hardship.

This notice shall take effect November 18, 1953.

BUSINESS AND DEFENSE
SERVICES ADMINISTRATION,
CHAS. F. HONEYWELL,
Administrator.

SCHEDULE A

Titanium sponge and titanium metal (ingot and mill products).

BUSINESS AND DEFENSE SERVICES ADMINISTRATION ORDER M-107 (MAY 10, 1954)—TITANIUM MILL PRODUCTS

This order is found necessary and appropriate to promote the national defense and is issued pursuant to the Defense Production Act of 1950, as amended. In the formulation of this order there has been consultation with industry representatives, including trade association representatives, and consideration has been given to their recommendations.

Sec.

1. What this order does.
2. Definitions.
3. Applicability of BDSA Reg. 2.
4. Limitations on required acceptance of rated orders.
5. Scheduling of deliveries pursuant to rated orders.
6. Requests for adjutment or exception.
7. Records and reports.
8. Communications.
9. False statements.
10. Violations.

AUTHORITY: Sections 1 to 10 issued under sec. 704, 64 Stat. 816, Pub. Law 95, 83d Cong.; 50 U. S. C. App. Sup. 2154. Interpret or apply sec. 101, 64 Stat. 799, Pub. Law 95, 83d Cong.; 50 U. S. C. App. Sup. 2071 E. O. 10480, Aug. 14, 1953, 18 F. R. 4939.

Section 1. What This Order Does. This order limits the obligation of producers of titanium mill products to accepted rated orders for such products. The order also provides for the scheduling of deliveries of titanium mill products pursuant to rated orders.

Sec. 2. Definitions. As used in this order:

(a) "Person" means any individual, corporation, partnership, association, or any other organized group of persons, and includes any agency of the United States Government or of any other government.

(b) "BDSA" means the Business and Defense Services Administration of the United States Department of Commerce.

(c) "APRA" means the Aircraft Production Resources Agency of the Department of Defense.

(d) "Titanium mill products" means commercially pure titanium or titanium alloy in the following forms: Ingot, billet, sheet, strip, plate, rod, bar, wire, tubing, extruded shapes, and rolled structural shapes.

(e) "Commercially pure titanium" means unalloyed titanium made by commercial production methods, with a titanium content of 99 percent or more by weight and containing fractional percentages of such elements as carbon, nitrogen, oxygen, or iron.

(f) "Titanium alloy" means a ductile titanium-base alloy containing 50 percent or more titanium by weight and lesser percentages of other metals and/or interstitial elements.

(g) "Producer" means any person who produces commercially pure titanium or titanium alloy by melting titanium sponge and/or titanium scrap; any such person's "production of titanium mill products" means the production by him, or by other persons for his account, of titanium mill products in the form in which they are to be physically delivered to purchasers pursuant to orders accepted by him. A person who produces titanium mill products from other titanium mill products but who does not produce commercially pure titanium or titanium alloy by melting titanium sponge and/or titanium scrap is not deemed a "producer" for the purposes of this order.

Sec. 3. Applicability of BDSA Reg. 2. The provisions of BDSA Reg. 2 (formerly NPA Reg. 2) are superseded to the extent that they are inconsistent with the provisions of this order. In all other respects the provisions of BDSA Reg. 2 shall remain in full force and effect.

Sec. 4. Limitations on Required Acceptance of Rated Orders. Unless specifically directed by BDSA, no producer of titanium mill products shall be required to accept rated orders calling for delivery during any calendar month, commencing with the month of June 1954, of an aggregate quantity of titanium mill products by weight which exceed 90 percent of his scheduled production of such products for that calendar month: *Provided, however,* That no producer shall cancel or postpone delivery of any rated orders already accepted because such orders exceed 90 percent of his scheduled production for that month.

Sec. 5. Scheduling of Deliveries Pursuant to Rated Orders. (a) Not later than the fifteenth day of any calendar month, commencing with the month of June 1954, each producer of titanium mill products shall furnish in writing to APRA, care of Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio, a detailed schedule of his projected production of titanium mill products pursuant to rated orders for delivery during that month and each of the next two succeeding months. Such schedules shall show substantially the following information with respect to each accepted rated order calling for delivery of titanium mill products during the 3-month period covered by the schedule, together with such further information as BDSA may from time to time require: customer's name and address, customer's purchase order date and number, the mill order number, the defense contract number, the DO rating, the form or shape, the alloy or grade, sizes, estimated total weight in pounds, pounds shipped against such order in the preceding month and in prior months and pounds scheduled for shipment during each of the months covered by this schedule.

(b) APRA will transmit each producer's schedule to the Department of Defense, Washington 25, D. C., together with APRA's recommendations thereon. The Department of Defense will transmit each producer's schedule to BDSA. together with its recommendations thereon, not later than 7 days prior to the end of the first month shown on such schedule. BDSA will review such schedules, together with the Department of Defense recommendations thereon, and will issue to each producer not later than 3 days prior to the end of the first month shown on such schedule a directive covering his production of titanium mill products to fill rated orders during the two succeeding months.

Sec. 6. Requests for Adjustment or Exception. Any person subject to any provision of this order may file a request for adjustment or exception upon the ground that such provision works an undue or exceptional hardship upon him not suffered generally by others in the same trade or industry, or that its enforcement against him would not be in the interest of the national defense or in the public interest. The filing of a request for adjustment or exception shall not relieve any person of his obligation to comply with any such provision. In examining requests for adjustment or exception claiming that the public interest is prejudiced by the application of any provision of this order, consideration will be given to the requirements of public health and safety, civilian defense, and dislocation of labor and resulting unemployment that would impair the defense program. Each request shall be in writing, by letter in triplicate, shall set forth all pertinent facts and the nature of the relief sought, and shall state the justification therefor.

Sec. 7. Records and Reports. (a) Each person participating in any transaction covered by this order shall make, and preserve for at least 2 years thereafter, accurate and complete records of receipts and deliveries in sufficient detail to permit the determination, after audit, whether each transaction complies with the provisions of this order. This order does not specify any particular accounting method and does not require alteration of the system of records customarily used, provided such records supply an adequate basis for audit. Records may be retained in the form of microfilm or other photographic copies instead of the originals.

(b) Each producer shall, not later than the fifteenth day of each month (commencing with June 15, 1954), complete and file Form BDSAF-263 in accordance with instructions accompanying the form.

(c) Persons subject to this order shall make such records and submit such further reports to BDSA as it shall require, subject to the terms of the Federal Reports Act of 1942 (5 U. S. C. 139-139F).

Sec. 8. Communications. All communications concerning this order, except as otherwise specified in this order, shall be addressed to the Business and Defense Services Administration, Washington 25, D. C., Ref: BDSA Order M-107.

Sec. 9. False Statement. The furnishing of false information or the concealment of any material fact in the course of operation under this order constitutes a violation of this order.

Sec. 10. Violations. Violation of any provision of this order may subject any person committing or participating in such violation to administrative action to require compliance with this order and correction of such violation. In addition to such administrative action, an injunction and order may be obtained prohibiting any such violation and enforcing compliance with the provisions hereof. Any person who wilfully violates any provisions of this order, or who wilfully furnishes false information or conceals any material fact in the course of operation under this order, is guilty of a crime and upon conviction may be punished by fine or imprisonment or both.

NOTE: All reporting and record-keeping requirements of this order have been approved by the Bureau of the Budget in accordance with the Federal Reports Act of 1942.

This order shall take effect May 19, 1954.

BUSINESS AND DEFENSE
SERVICES ADMINISTRATION,
By GEORGE W. AUXIER,
Executive Secretary.

OFFICE OF PRICE STABILIZATION, ECONOMIC STABILIZATION AGENCY, GENERAL OVERRIDING REGULATION 9¹—EXEMPTION OF CERTAIN INDUSTRIAL MATERIALS AND MANUFACTURED GOODS

RUTILE ORES AND CONCENTRATES

Pursuant to the Defense Production Act of 1950, as amended (Pub. Law 774, 81st Cong., Pub. Law 96, 82d Cong.), Executive Order 10161 (15 F. R. 6105), and Economic Stabilization Agency General Order No. 2 (16 F. R. 738), this amendment to General Overriding Regulation 9, is hereby issued.

STATEMENT OF CONSIDERATIONS

This amendment to General Overriding Regulation 9 exempts from price control all sales of imported and domestic rutile ores and concentrates, and the allied services of mining and processing such materials. Rutile is a natural titanium dioxide mineral used in the manufacture of welding rods, ferrotitanium products and titanium metal.

The annual sales of rutile in the United States are estimated to be substantially less than five million dollars. Certain pricing problems have arisen with respect to this material, and it has become apparent that appropriate solution for these problems would involve time and effort quite disproportionate to the importance of this commodity in the stabilization program. An appropriate price action for rutile would have to deal with many complex circumstances. Approximately 50 percent of this material is imported, the largest source being Australia, while the other 50 percent is mined domestically. Different price problems arise in each of these connections. With respect to the imported supply, the price must be set high enough to permit United States importers to bid in the world market. With respect to the domestic portion of the supply, there have been recent changes in the recovery rate of the ore, and further study would be required to discover an appropriate price in view of these changed circumstances. In addition, prices or margins would have to be established for various processors and handlers of this material, both when domestically produced and when imported. The establishment of such margins would be further complicated by the fact that the market for zircon, a corollary material produced in the mining of rutile, has been depressed. A pricing action which would appropriately recognize all of these difficulties would require time and effort out of proportion to the economic significance of the commodity.

Yet rutile is a vital material in the defense program. Ferrotitanium alloys are used by the major metal industries in the nation. The metal titanium has many strategic applications in the defense program where it is being used increasingly for aircraft, ordnance, submarine parts, jet engines, rockets, as well as having classified applications in the atomic energy field. The increased requirements of the defense program will call for substantially increased domestic production and importation of rutile ores and concentrates. Because of the vital character of this commodity to the defense program, any substantial delay in working out an appropriate structure of price controls might interfere with the progress of the defense effort.

For the reasons set forth above, the Director has determined that this is an appropriate instance for the

¹ Amendment 13.

exercise of his authority to exempt commodities from price control.

In formulating this amendment, the Director of Price Stabilization has consulted with industry representatives and has given consideration to their recommendations.

AMENDATORY PROVISIONS

General Overriding Regulation 9 is amended in the following respects:

1. Section 2 (a) (23) is added to read as follows:

(23) **Sales of Rutile Ores and Concentrates and Services of Mining and Processing Rutile Ores and Concentrates.** "Rutile ores and concentrates" includes any rutile ore in a crude state or in concentrated, beneficiated or sized form. "Mining and processing" includes extraction, concentration, beneficiation, cleaning, grinding and repackaging.

(Sec. 704, 64 Stat. 816, as amended; 50 U. S. C. App. Sup. 2154.)

Effective Date. This Amendment 13 to General Overriding Regulation 9 shall become effective January 18, 1952.

MICHAEL V. DiSALLE,
Director of Price Stabilization.

JANUARY 18, 1952.

NATIONAL SECURITY RESOURCES BOARD— ISSUANCE OF NECESSITY CERTIFICATES UNDER SECTION 124A OF THE INTERNAL REVENUE CODE

The following regulation is hereby prescribed by the Chairman of the National Security Resources Board, with the approval of the President, pursuant to the authority contained in Executive Order 10172, dated October 12, 1950.

Sec.

600.1 Definitions.

600.2 Criteria for determination of necessity and of portion attributable to defense purposes.

600.3 Procedures and responsibilities.

600.4 Exercise of powers of certifying authority.

600.5 Amendment of this part.

AUTHORITY: §§ 600.1 to 600.5 issued under sec. 124A, as added by sec. 216, Pub. Law 814, 81st Cong., E. O. 10172, Oct. 12, 1950, 15 F. R. 6929.

§ 600.1 Definitions. As used throughout this part:

(a) "Emergency facility" means any facility, land, building, machinery or equipment, or any part thereof, the construction, reconstruction, erection, installation, or acquisition of which was completed after December 31, 1949, and with respect to which a Necessity Certificate has been made.

(b) "Emergency period" means the period beginning January 1, 1950, and ending on the date on which the President proclaims that the utilization of a substantial portion of the emergency facilities with respect to which Necessity Certificates have been made is no longer required in the interest of national defense.

(c) "Certifying authority" means the Chairman of the National Security Resources Board or his duly authorized representative.

(d) "Necessity Certificate" means a certificate made pursuant to section 124A of the Internal Revenue Code, certifying that the construction, reconstruction, erection, installation, or acquisition of the facilities referred to in the certificate is necessary in whole or in part in the interest of national defense during the emergency period, and certifying the portion thereof attributable to defense purposes.

(e) "Materials" means raw materials, articles, commodities, products, supplies and components.

(f) "Taxpayer" means a person as defined in section 3797 (a) (1) of the Internal Revenue Code.

§ 600.2 Criteria for Determination of Necessity and of Portion Attributable to Defense Purposes. Determination will be made as to whether the construction, reconstruction, erection, installation, or acquisition of the facility (in whole or in part) is necessary in the interest of national defense during the emergency period and what portion of the facility is attributable to defense purposes.

(a) **Materials or Services Required for National Defense.** In making such determination, consideration will be given to whether the material or service to be produced with the proposed emergency facility is required in whole or in part in the interest of national defense during the emergency period. A material or service may be found to be so required if it is directly required for the Armed Services of the United States or auxiliary personnel, for civil defense, for the Atomic Energy Commission, or for any operations or activities in connection with the Mutual Defense Assistance Act; or if it is in the nature of materials or services necessary for the production of materials or services directly required in the interest of national defense during the emergency period; or if it is in the nature of materials or services necessary for the operation of the national defense program; or if it is otherwise necessary in the interest of national defense.

(b) **Shortage of Facilities for the Production of Materials or Services Required for National Defense.** In making such determination, consideration will be given to whether at the time of the construction, reconstruction, erection, installation or acquisition of the facility, there is an existing or prospective shortage of facilities for the production of the materials or services which are to be produced by the facility sought to be certified. In such determination, consideration will be given to an over-all shortage, the necessity for and adequacy of facilities or materials or services for a particular region, the necessity for stand-by capacity, and other factors contributing to or threatening a shortage of facilities for producing such materials or services.

(c) **Economic Usefulness of the Facility.** In determining the portion of the facility attributable to defense purposes consideration will be given to the probable economic usefulness of the facility for other than defense purposes after five years.

(d) **Acquired Facilities, Replacements, and Land.**

(1) Acquired facilities previously constituting the productive assets of a going concern, and second-hand facilities, will not be certified unless:

(i) Clear prospect of a substantial increase in the usefulness of such facilities for national defense exists and such increase cannot be obtained by other practical means; or (ii) substantial loss of usefulness for national defense would probably result in the absence of such acquisition.

(2) Replacements will not be certified if they would have been made, at or about the time made, regardless of the emergency.

(3) Land will not be certified unless its acquisition is directly related to the production, storage, transportation or protection of supplies necessary in the interest of the national defense.

(e) **Other Considerations.** In making such determination, guidance to the maximum extent will be obtained from the following additional considerations:

(1) Assurance of fair opportunity for participation by small business; (2) the promotion of competitive enterprise; (3) the competence, performance record, if any, and other factors bearing upon the ability of the applicant to manage effectively the proposed expanded facilities; (4) location of the facility with due regard to military security; (5) the availability of manpower, housing, community facilities, transportation, and other elements of production; and (6) methods of financing.

§ 600.3 Procedures and responsibilities.—(a) *Application form.* Formal application filed after the effective date of this part shall conform to the standard form prescribed by the certifying authority, and shall be executed in the manner and by the person prescribed by the form. The standard form of application for a Necessity Certificate with accompanying instructions may be obtained from the National Security Resources Board, Washington 25, D. C., or from the Department of Commerce or any of its field offices.

(b) *Filing of application.* All applications for Necessity Certificates filed under the terms of this part shall be filed with the National Security Resources Board in Washington, D. C., and shall be deemed to be filed when received at that Board. If the application or its filing would involve the disclosure of information which has a security classification, the applicant should check with the appropriate government agency with whom the applicant has classified contract relations for instruction or arrangements concerning the handling of such documents or data prior to the filing of such application with the National Security Resources Board.

(c) *Time of filing application.* (1) Applications for Necessity Certificates for facilities upon which construction, reconstruction, erection or installation is begun, or which are acquired, after September 23, 1950, must be filed within six (6) months after the beginning of construction, reconstruction, erection or installation, or the date of acquisition of such facilities.

(2) Applications for Necessity Certificates for facilities upon which construction, reconstruction, erection or installation was begun or which were acquired on or before September 23, 1950, must be filed on or before March 23, 1951.

(d) *Modification of filing requirements.* The time and place for filing applications for Necessity Certificates may be changed by the certifying authority. Such change shall be effective upon publication in the Federal Register.

(e) *Referral of application.* Each application, after acknowledgment, will be referred to that agency or officer of the Government according to its respective assigned responsibilities pursuant to the Defense Production Act of 1950.

(f) *Responsibilities of agencies and officers other than certifying authority.* Delegate agencies and officers shall be responsible for making a report and recommendation for specific action to the certifying authority regarding each application. Such report and recommendation shall be based upon a thorough examination and investigation conducted by the delegate agency or officer or by other competent government agencies or officers.

(g) *Action by the certifying authority.* After consideration of relevant factors, including but not limited to the report and recommendation of the delegate agencies and officers, the certifying authority will make the appropriate decision regarding the application.

(h) *Necessity Certificates.* Upon issuance of a Necessity Certificate, it will be forwarded to the Commissioner of Internal Revenue and will constitute conclusive evidence of certification by the certifying authority that the facilities therein described are necessary in the interest of national defense to the extent certified. The certifying authority will not certify the accuracy of the cost of any facility or of any date relative to the construction, reconstruction, erection, installation or acquisition thereof. It will be incumbent upon taxpayers electing to take the amortization deduction to establish to the satisfaction of the Commissioner of Internal Revenue the identities of the facilities, the costs thereof and the dates relative thereto.

(i) *Further description after certification.* Where after the completion of a construction, reconstruction,

erection, installation or acquisition of an emergency facility, the taxpayer finds that the description or cost of any facility appearing in the Necessity Certificate materially varies from the actual description or cost of the facility, a statement may be filed by the taxpayer with the certifying authority setting forth the correct description or cost of the emergency facility actually constructed, reconstructed, erected, installed or acquired. A copy of the statement will be forwarded by the certifying authority to the Commissioner of Internal Revenue, provided the description or cost in the opinion of the certifying authority is within the scope of the original certification, and when so forwarded, the statement will have the effect of an amendment of the original certificate.

(j) *Cancellation of amendment of Necessity Certificate.* The certifying authority may (1) cancel any Necessity Certificate where it has been obtained by fraud or misrepresentation or has been issued through error or inadvertence, or (2) amend any Necessity Certificate for sufficient cause shown.

§ 600.4 Exercise of Powers of Certifying Authority. Any actions taken in exercise of the powers and authority vested in the Chairman of the National Security Resources Board by E. O. 10172, October 12, 1950 (15 F. R. 6929) may be taken in the name of the National Security Resources Board, countersigned or attested by the Chairman's authorized representative.

§ 600.5 Amendment of This Part. This part may be amended by the Chairman of the National Security Resources Board with the approval of the President.

W. STUART SYMINGTON,
Chairman, National Security
Resources Board.

H. DEWAYNE KREAGER,
Secretary National Security
Resources Board.

Approved:

HARRY S. TRUMAN,
The White House.

DEFENSE MINERALS EXPLORATION ADMINISTRATION ORDER 1—GOVERNMENT AID IN DEFENSE EXPLORATION PROJECTS

This order is found to be necessary and appropriate to carry out the provisions of the Defense Production Act of 1950, as amended, with reference to the encouragement of exploration, development, and mining of critical and strategic minerals and metals pursuant to section 303 (a) of the act. It supersedes Mineral Order 5 of the former Defense Minerals Administration. In the formulation of this order there has been consultation with industry representatives, including trade association representatives, and consideration has been given to their recommendations.

EXPLANATORY PROVISIONS

Sec.

1. What this order does.
2. Definitions.

APPLICATIONS

3. Form and filing.
4. Scope of application.
5. Action on applications.
6. Criteria.

EXPLORATION PROJECT CONTRACTS

7. Ratio of contributions.
8. Operator's property rights.
9. Allowable costs.
10. Repayment by operator.
11. Title to and disposition of property.

AUTHORITY: Sections 1 to 11 issued under sec. 704, 64 Stat. 816, Pub. Law 96, 82d Cong.; 50 U. S. C. App. Sup. 2154, Interpret or apply sec.

303, 64 Stat. 801, Pub. Law 96, 82d Cong.; 50 U. S. C. App. Sup. 2093, E. O. 10161, Sept. 9, 1950, 15 F.R. 6105; 3 CFR, 1950 Supp. E. O. 10281, Aug. 28, 1951, 16 F. R. 8789.

EXPLANATORY PROVISIONS

Section 1. What This Order Does. This order sets forth procedures and regulations for obtaining Government aid in financing the cost of projects for exploration for unknown or undeveloped sources of strategic or critical metals and minerals.

Sec. 2. Definitions. As used in this order:

(a) "Exploration project" means the search for unknown or undeveloped sources of strategic or critical metals or minerals within a specified area or parcel of ground in the United States, its territories or possessions, whether conducted from the surface or underground, including recognized and sound procedures for obtaining pertinent geological, geophysical, and geochemical information. The work shall not go beyond a reasonable delineation and sampling of the ore, and shall not include work

prosecuted primarily for mining or preparation for mining.

(b) "Operator" means a person, firm, partnership, corporation, association, or other legal entity by whom or for whose account and interest an exploration project is to be carried out.

(c) "Administrator" means the Administrator of Defense Minerals Exploration Administration, or his representative authorized in writing.

(d) "Government" means the United States of America.

APPLICATIONS

Sec. 3. Form and Filing. An application for aid in any specified exploration project must be in quadruplicate on forms which may be obtained from and filed with either:

The Defense Minerals Exploration Administration, Department of the Interior, Washington 25, D. C.

or the nearest Defense Minerals Exploration Administration field executive officer as indicated by the following addresses:

Region	Area served	Address
I.....	Alaska.....	Bureau of Mines, P. O. Box 2990, Juneau, Alaska.
II.....	Washington, Oregon, Idaho, and Montana.....	South 157 Howard Street, Spokane 8, Wash.
III.....	California and Nevada.....	1012 Flood Building, 870 Market Street, San Francisco 2, Calif.
IV.....	Arizona, New Mexico, Colorado, Utah, and Wyoming.....	Bureau of Mines, 224 New Customhouse Building, Denver 2, Colo.
V.....	North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Wisconsin, and Michigan.....	2098 Colfax Avenue, South Minneapolis 8, Minn.
VI.....	Kansas, Louisiana, Oklahoma, Texas, Arkansas, and Missouri.....	221 West Third Street, Joplin, Mo.
VII.....	Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, and Mississippi.....	Room 13, Post Office Building, Knoxville, Tenn.
VIII.....	Illinois, Indiana, Ohio, Kentucky, Virginia, West Virginia, Maryland, Massachusetts, New York, Vermont, Maine, New Hampshire, Connecticut, Rhode Island, New Jersey, Delaware, and Pennsylvania.....	Bureau of Mines, Eastern Experiment Station, College Park, Md.

Sec. 4. Scope of Application. Each application shall relate to and fully describe a single exploration project, which shall be justified by detailed substantiating data as called for by the application form. The Administrator may require the filing of additional information, reports, maps, or charts, and exhibits, in connection with the application, and may make such physical examination of the project as he deems necessary.

Sec. 5. Action on Applications. If the application is approved, the Government, acting through the Administrator, will enter into an exploration project contract with the applicant upon such terms and conditions as are set forth in the contract form which the Administrator will supply. Exploration projects the estimated time for the performance of which is more than two years will be approved only if justified, in the opinion of the Administrator, by special circumstances.

Sec. 6. Criteria. The following factors will be considered and weighed in passing upon applications:

- The strategic importance of the mineral involved.
- The geologic probability of making a significant discovery.
- The availability of manpower, materials, supplies, equipment, water, and power.
- The accessibility of the project.
- The operating experience and background of the applicant.

EXPLORATION PROJECT CONTRACTS

Sec. 7. Ratio of Contributions. The Government, upon the terms specified in the contract, will contribute a percentage of the total cost of a project, depending upon the mineral or minerals which are the subject of exploration, as follows:

(a) In the case of chromium, copper, fluor spar, crucible flake graphite, iron ore, lead, molybdenum, sulfur, catalytic grade halloysite, bauxite, zinc and cadmium—50 percent.

(b) In the case of antimony, manganese, mercury, tungsten, rutile and brookite—75 percent.

(c) In the case of chrysotile and amosite asbestos, beryl, cobalt, columbium-tantalum, corundum, cryolite, industrial diamonds, strategic kyanite, strategic mica; monazite, uranium, and rare-earth ores; nickel, platinum-group metals, piezo-electric quartz crystals, block steatite talc, and tin—90 percent.

(d) In the event that two or more of the minerals named in this section are the subject of the proposed exploration the allowable percentage shall be apportioned between them.

Sec. 8. Operator's Property Rights. The Operator must have, preserve, and maintain a sufficient interest in the land, as owner, lessee, or otherwise, for the purposes of the exploration project contract. The Operator shall devote the land and all existing improvements, facilities, buildings, installations, and appurtenances to the purposes of the exploration project without any

allowance for the use, rental value, depreciation, depletion, or other cost of acquiring, owning, or holding possession thereof.

Sec. 9. Allowable Costs. (a) The Government, to the extent provided in the exploration project contract, will contribute to the necessary, reasonable, direct costs of performing the exploration work, including the costs of labor, supervision, and consultants; workmen's compensation and employers' liability insurance and payroll and sales taxes; operating materials and supplies; operating equipment to be rented or purchased, or which is owned and will be furnished by the Operator; necessary rehabilitation or repairs of existing buildings, installations, fixtures, and movable operating equipment owned by the Operator and devoted to the purposes of the exploration project contract; necessary buildings, fixed improvements, or installations to be purchased, installed, or constructed for the purposes of the exploration work; repairs to and maintenance of operating equipment in the course of operations; analytical work; accounting; amounts paid by the Operator to independent contractors; costs estimated and agreed upon by the Operator and the Government in terms of units of work performed (per foot of drifting, per foot of drilling, etc.); and such other necessary, reasonable, direct costs as may be approved by the Government in the course of the work.

(b) No items of general overhead, corporate management, interest, taxes (other than payroll and sales taxes), or any other indirect costs, or work performed or costs incurred before the date of the contract, shall be allowed as costs of the project in which the Government will participate.

Sec. 10. Repayment by Operator. (a) If, at any time, the Government considers that a discovery or a development from which production may be made has resulted from the exploration work, the Government, at any time not later than six months after the Operator has rendered any final report and final account, may so certify in writing to the Operator. The certification shall describe broadly or indicate the nature of the discovery or development. In the event of such certification, any minerals mined or produced from the land which is the subject of the exploration project contract within ten years from the date of the contract, including any mined or produced before the certification, shall be subject to a percentage royalty which the Operator or his successor in interest shall pay to the Government, upon the net smelter returns, the net concentrator returns, or other net amounts realized from the sale or other disposition of any such production, in whatever form disposed of, including ore, concentrates, or metal, until the total amount contributed by the Government, without interest, is fully repaid, or said ten years have elapsed, whichever occurs first, as follows:

(1) One and one-half ($1\frac{1}{2}$) percent of any such net amounts not in excess of eight dollars (\$8.00) per ton.

(2) One and one-half ($1\frac{1}{2}$) percent of any such net amounts, plus one-half ($\frac{1}{2}$) percent of such net amounts for each additional full fifty cents (\$0.50) by which such net amounts exceed eight dollars (\$8.00) per ton, but not in excess of five (5) percent of such net amounts.

(For instance: the percentage royalty on a net amount of five dollars (\$5.00) per ton, would be one and one-half ($1\frac{1}{2}$) percent; on a net amount of ten dollars (\$10.00) per ton, three and one half ($3\frac{1}{2}$) percent.)

(b) As here used, "net smelter returns," "net concentrator returns," and "other net amounts realized from the sale or other disposition," mean gross revenue from sales; or if not sold, the market value of the material after it is mined in the form in which and the place where it is held. In the case of integrated operations in which the material is not disposed of as such, these terms mean what is or would be gross income from min-

ing operations for percentage depletion purposes in income tax determination.

(c) To secure the payment of its percentage royalty, the exploration project contract shall provide for a lien upon the land or the Operator's interest in the land which is the subject of the contract and upon any production of minerals therefrom, and personal liability of the Operator if he fails to preserve the lien, until the royalty claim is extinguished by lapse of time or is fully paid, or is otherwise satisfied or extinguished as provided in the contract.

(d) This section is not to be construed as imposing any obligation on the Operator or the Operator's successor in interest to engage in any mining or production operations.

Sec. 11. Title to and Disposition of Property. All facilities, buildings, fixtures, equipment, or other items costing more than \$50.00 each, paid for or purchased with funds contributed jointly by the Operator and the Government, although title may be taken in the name of the Operator, shall belong to the Operator and the Government jointly, in proportion to their respective contributions, and the exploration project contract shall make suitable provisions for their disposal for the joint account of the Operator and the Government.

Dated: March 7, 1952.

C. O. MITTENDORF,
Acting Administrator,
Defense Minerals Exploration Administration.

OFFICE OF DEFENSE MOBILIZATION MATERIALS MEMORANDUM V-1 (REVISED)¹ —CURRENT LIST OF STRATEGIC AND CRITICAL MATERIALS FOR STOCKPILING

Section 1. Purpose. This memorandum is issued pursuant to Section 2 (a) of Public Law 520, 79th Congress. The materials as listed herein comprise those currently included in the stockpiling program. It should be noted that not all of the listed materials are under active procurement.

Sec. 2. Group I Materials. The materials listed in this section constitute Group I and have been or may be acquired through purchase pursuant to Section 3 (a) and by transfer of Government-owned surpluses pursuant to Section 6 (a) of Public Law 520, 79th Congress.

1. Abrasive, Crude Aluminum Oxide
2. Aluminum
3. Antimony
4. Asbestos, Amosite
5. Asbestos, Chrysotile
6. Asbestos, Crocidolite
7. Bauxite, Metal Grade
8. Bauxite, Refractory Grade
9. Beryl
10. Bismuth
11. Bristles, Hog
12. Cadmium
13. Castor Oil
14. Celestite
15. Chromite, Chemical Grade
16. Chromite, Metallurgical Grade
17. Chromite, Refractory Grade
18. Cobalt
19. Coconut Oil
20. Columbite
21. Copper
22. Cordage Fibers, Abaca
23. Cordage Fibers, Sisal
24. Corundum

¹ February 14, 1955.

25. Cotton, Extra Long Staple
26. Diamonds, Industrial
27. Feathers and Down, Waterfowl
28. Fluorspar, Acid Grade
29. Fluorspar, Metallurgical Grade
30. Graphite, Amorphous Lump
31. Graphite, Crucible Grade
32. Graphite, Lubricant and Packing Grade
33. Hyoscine
34. Iodine
35. Jewel Bearings, Instrument Jewel except Vee Jewels
36. Jewel Bearings, Sapphire and Ruby Vee Jewels
37. Jewel Bearings, Watch and Timekeeping Device Jewels
38. Lead
39. Magnesium
40. Manganese Ore, Battery Grade
41. Manganese Ore, Chemical Grade
42. Manganese Ore, Metallurgical Grade
43. Mercury
44. Mica, Muscovite Block, Stained and Better
45. Mica, Muscovite Film, First and Second Qualities
46. Mica, Muscovite Splittings
47. Mica, Phlogopite Splittings
48. Molybdenum
49. Nickel
50. Opium
51. Palm Oil
52. Platinum Group Metals, Iridium
53. Platinum Group Metals, Platinum
54. Pyrethrum
55. Quartz Crystals
56. Quinidine
57. Rare Earths
58. Rubber, Crude Natural
59. Sapphire and Ruby
60. Selenium
61. Shellac
62. Silicon Carbide (Crude)
63. Silk, Raw

64. Silk Waste and Noils
65. Sperm Oil
66. Tale, Steatite, Block
67. Tantalite
68. Tin
69. Titanium Sponge
70. Tungsten
71. Vanadium
72. Vegetable Tannin Extract, Chestnut
73. Vegetable Tannin Extract, Quebracho
74. Vegetable Tannin Extract, Wattle
75. Zinc

Sec. 3. Group II Materials. The materials listed in this section have been acquired principally through transfer of Government-owned surpluses pursuant to Section 6 (a) of Public Law 520, 79th Congress, and constitute Group II. None is under procurement.

1. Agar
2. Bauxite, Abrasive
3. Cryolite, Natural
4. Diamond Dies
5. Emetine
6. Graphite, Crystalline Fines
7. Mica, Muscovite Block, Stained and Lower
8. Mica, Phlogopite Block
9. Optical Glass
10. Platinum Group Metals, Osmium
11. Platinum Group Metals, Palladium
12. Platinum Group Metals, Rhodium
13. Platinum Group Metals, Ruthenium
14. Rutile
15. Tale, Steatite, Ground
16. Wool
17. Zirconium Ore, Baddeleyite
18. Zirconium Ore, Zircon

Sec. 4. Effective Date. This memorandum supersedes Materials Memorandum V-MAT-MM-1 (Revised) dated July 15, 1954, and is effective immediately.

W. S. FLOYD,
Assistant Director of ODM for Materials.

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